NATIONAL BUREAU OF STANDARDS REPORT

6526

EVALUATION OF RESISTANCE STRAIN GAGES
AT ELEVATED TEMPERATURES

Progress Report No. 8

by

R. L. Bloss, C. H. Melton and J. T. Trumbo

NBS

U. S. DEPARTMENT OF COMMERCE
NATIONAL BUREAU OF STANDARDS

THE NATIONAL BUREAU OF STANDARDS

Functions and Activities

The functions of the National Bureau of Standards are set forth in the Act of Congress, March 3, 1901, as amended by Congress in Public Law 619, 1950. These include the development and maintenance of the national standards of measurement and the provision of means and methods for making measurements consistent with these standards; the determination of physical constants and properties of materials; the development of methods and instruments for testing materials, devices, and structures; advisory services to Government Agencies on scientific and technical problems; invention and development of devices to serve special needs of the Government; and the development of standard practices, codes, and specifications. The work includes basic and applied research, development, engineering, instrumentation, testing, evaluation, calibration services, and various consultation and information services. A major portion of the Bureau's work is performed for other Government Agencies, particularly the Department of Defense and the Atomic Energy Commission. The scope of activities is suggested by the listing of divisions and sections on the inside of the back cover.

Reports and Publications

The results of the Bureau's work take the form of either actual equipment and devices or published papers and reports. Reports are issued to the sponsoring agency of a particular project or program. Published papers appear either in the Bureau's own series of publications or in the journals of professional and scientific societies. The Bureau itself publishes three monthly periodicals, available from the Government Printing Office: The Journal of Research, which presents complete papers reporting technical investigations; the Technical News Bulletin, which presents summary and preliminary reports on work in progress; and Basic Radio Propagation Predictions, which provides data for determining the best frequencies to use for radio communications throughout the world. There are also five series of nonperiodical publications: The Applied Mathematics Series, Circulars, Handbooks, Building Materials and Structures Reports, and Miscellaneous Publications.

Information on the Bureau's publications can be found in NBS Circular 460, Publications of the National Bureau of Standards ($1.25) and its Supplement ($0.75), available from the Superintendent of Documents, Government Printing Office, Washington 25, D. C.

Inquiries regarding the Bureau's reports should be addressed to the Office of Technical Information, National Bureau of Standards, Washington 25, D. C.

NATIONAL BUREAU OF STANDARDS REPORT

NBS PROJECT		NBS REPORT
0604-20-06441	August 1959	6526

Evaluation of Resistance Strain Gages
at Elevated Temperatures

Progress Report No. 8

by

R. L. Bloss, C. H. Melton and J. T. Trumbo

Engineering Mechanics Section
Division of Mechanics

Technical Report
to
Bureau of Aeronautics
Wright Air Development Center

Order No. NAer 01901

NBS

U. S. DEPARTMENT OF COMMERCE

NATIONAL BUREAU OF STANDARDS

FOREWORD

In recent years the use of structures at elevated temperatures has increased greatly. If the safe design and efficient use of structural materials are to be assured, a knowledge of the properties of materials and of structural configurations is essential. In determining these properties, the measurement of strains and deformations is important. Strain gages to measure these quantities must be capable of operating satisfactorily over a wide temperature range.

In order to determine the characteristics of strain gages which are available for use at elevated temperatures, the Department of the Navy and the Department of the Air Force have sponsored a program for the evaluation of these gages. This report is one of a series giving the results of these evaluation tests.

There is a continuing effort on the part of manufacturers and research organizations to develop improved strain gages for use at elevated temperatures. Therefore the results given in this report would not necessarily show the performance of similar gages which may differ in characteristics due to differences in materials, treatments, or methods of fabrication.

L. K. Irwin
Chief, Engineering Mechanics Division

B. L. Wilson
Chief, Mechanics Division

CONTENTS

Evaluation of Resistance Strain Gages at Elevated Temperatures

Progress Report No. 8

by

R. L. Bloss, C. H. Melton and J. T. Trumbo

SYNOPSIS

Resistance strain gages of the SS-E-4D-A series, manufactured by Micro-Test, Inc., were evaluated at elevated temperatures. The characteristics determined were (1) gage factor at room temperature, (2) variation of gage factor with increasing temperature, (3) drift, (4) resistance-temperature relationship, (5) behavior under transient heating conditions, and (6) behavior when subjected to large strains. The results of these tests indicate that these gages, when attached to stainless steel, have repeatable gage factor characteristics, a very low temperature coefficient of resistance, low drift at temperatures up to 700° F, and the ability to withstand large tensile strains without failure.

1. INTRODUCTION

In the continuing evaluation of resistance strain gages designed for use at elevated temperatures, gages manufactured by Micro-Test, Inc. were subjected to evaluation tests. The gages tested were type SS-E-4D-A. The gages were subjected to tests to determine the following characteristics:

(1) Gage factor at about 75° F,

(2) Variation of gage factor with increasing temperature,

(3) Relative change of resistance with time (drift),

(4) Resistance-temperature relationship,

(5) Behavior under transient heating conditions, and

(6) Behavior when subjected to large strain.

The manufacturer does not recommend these gages for static strain measurements at temperatures above 850° F.

The results of previous evaluations of other gage types are given in references 1 through 7.

2. GAGES

The gages which are reported on herein were purchased from Micro-Test, Inc. The active element is made by etching the center section of a 0.007 inch diameter wire to a diameter of 0.001 inch. The unreduced ends form the leads of the gage, thereby producing a gage element with no internal joints. This filament is imbedded in an insulating material within a metal tube. The metal tube is welded to a thin sheet which, in turn, is attached to a structure or test specimen, usually by spotwelding. The gages tested were made from two of these elements as shown in figure 1.

The gages were attached to stainless steel test strips by spotwelding. In most cases the spotwelding was done with the hand tweezer assembly of a Unitek Model 1015 spotwelder. A small number of gages were attached with a Rollectrode* attachment for the Unitek Model 1015 spotwelder. The installation instructions of the manufacturer were followed.

3. TEST EQUIPMENT AND METHODS

The equipment and methods used for all evaluation tests except those for determining the variation of gage factor with increasing temperature are described in references 5 and 8.

The variation of gage factor with temperature was determined from tests with the equipment shown schematically in figures 2 and 3. Two gages are mounted on each side of a constant strength cantilever beam near its fixed end. The four gages are then connected to form a complete bridge circuit. The free end of the beam is attached to an electro-mechanical vibrator by a rigid connecting rod. The power to the radiant heaters is controlled so that the temperature of the beam is increased at a nearly uniform rate. A low temperature gradient is maintained over the beam length by controlling the power to heating elements in the clamping fixture.

The open circuit output voltage of a bridge circuit made up of identical gages in all four arms with all gages subjected to strain of the same magnitude, two gages in tension and two gages in compression and arranged for maximum bridge unbalance, is approximately

$$E_o = E_i K \epsilon$$

---

* Micro-Test, Inc.

where E_i = the input voltage

K = gage factor of the gages

ϵ = strain (magnitude) to which the gages are subjected.

If the strain is periodic and the other two factors are constant or vary slowly, the output signal will be an alternating voltage of the same frequency as the vibration of the beam. Variations in the amplitude of this alternating voltage during a test in which the input voltage and vibration amplitude are constant will be due to changes in the gage factor and changes in the strain magnitude resulting from thermal expansion of the beam. Changes in the output signal due to lack of compensation for drift and for temperature coefficient of resistance will be slow compared to the frequency of vibration. These slowly varying signals will be rejected by suitable circuitry. The effect of the thermal expansion of the beam can be readily computed from beam theory and the data adjusted to correct for this effect.

In order to obtain sufficient sensitivity to show small changes of gage factor, the small output signal (a few millivolts) is amplified, rectified, and suppressed so that a change of bridge circuit output voltage of about 20 percent of its nominal value will produce full Y-scale deflection of an X-Y recorder.

Just prior to starting a test, the sensitivity of the Y-axis of the recorder is determined in the following manner:

(1) The amplitude of vibration is adjusted to the desired level.

(2) The input voltage is set at its nominal value.

(3) The amplifier gain is adjusted to give the desired signal level as indicated by the recorder.

(4) The signal to the recorder is completely suppressed.

(5) The recorder sensitivity (Y-axis) is increased so that a 10 percent change of signal level will produce about one-half of full scale deflection.

(6) The input voltage to the bridge circuit is varied from about 90 percent to about 110 percent of its nominal value.

(7) The Y-scale is marked in convenient steps. Each step usually corresponds to a change of 2 percent of the nominal input voltage.

The temperature, amplitude of vibration, and gage factor are assumed to be constant during this time. The effect of the input voltage changes is the same as would be produced by equal percentage changes of gage factor with constant input voltage and strain level. Although both gage factor and strain level usually change during a test, the combined effects of these changes can be considered to be the sum of the individual effects provided each is small.

After the Y-axis sensitivity is adjusted and calibrated, the input voltage is returned to its nominal value. The temperature of the beam is increased at about 20° F per minute while the input voltage and vibration amplitude are kept constant. As the temperature increases, the variation of bridge circuit output voltage is recorded as a function of temperature. The recorded data are adjusted to correct for the effect of thermal expansion of the beam giving a record of the variation of gage factor with increasing temperature.

4. RESULTS

The number of gages subjected to the various tests is shown in table 1. The results of the evaluation tests are given in table 2 and figures 4 through 31.

4.1 Strain Sensitivity

Gage factor values were obtained at about 75° F from three gages for a maximum strain of about 0.001 in tension and compression. These values are given in table 2 where

K_u = gage factor for increasing load

K_d = gage factor for decreasing load

$\overline{K}$ = average gage factor value.

Gages 6.4-A_1 and 6.4-A_3 were tested in tension before being tested in compression. Gage 6.4-A_2 was tested in compression before being tested in tension. All of the gage factor values obtained were within the range specified by the manufacturer, 1.8 ± 5 percent. The average of all values obtained was within 1-1/2 percent of the manufacturer's nominal value. For any one gage, no value differed from the average for that gage by as much as 2-1/2 percent.

The variation of gage factor with increasing temperature is shown in figures 4 through 7. Each of the curves of figures 4 through 6 show the average change of gage factor for the four gages which were mounted on a

beam and connected into a bridge circuit. Each curve of figure 7 represents the average result for four tests of one set of four gages. At temperatures up to 800° F, gage factor values indicated for only two test runs differ from the average for all runs by more than 3 percent of the room temperature value. These differences exceed 3 percent only at temperatures above 780° F.

4.2 Drift

The drift behavior of individual gages at each test temperature is shown in figures 8 through 17. Each curve of figure 18 represents the average of the results for two gages. The drift values at temperatures as high as 700° F were small. At temperatures of 800° F and above, the drift was much greater, and considerable difference was found between the values obtained for two gages. The greatest drifts were obtained at 1000° F and 1100° F with a much lower drift being shown at 1200° F. Since the gages were tested at each test temperature in ascending order, the lower drift shown at 1200° F might not be representative of a gage which had not been held at lower temperatures. At all test temperatures from 800° F to 1200° F the drift was too high to permit a complete evaluation of the gages for static strain conditions.

4.3 Temperature Sensitivity

The temperature coefficient values obtained for two gages are shown in figure 19. The values plotted are the slopes of lines drawn tangent to recorded curves of relative change of resistance as a function of temperature. The values obtained for the first run of each gage are somewhat different than those obtained on subsequent runs. The values obtained for the second and third run were nearly the same for both gages. In all cases the temperature coefficient was small. It should also be noted that the temperature coefficient values passed through zero so that the total resistance change for a large temperature change might be very small.

Figures 20 through 22 show the relative change of resistance of three gages for five heating cycles to about 600° F followed by five heating cycles to about 800° F. The average heating rate was 5° F/sec to 10° F/sec. The behaviors of two of the gages (6.4-T_4 and 6.4-T_5) were nearly the same, and, after the first heating cycle to each temperature, the behavior of each of these gages was repeatable. The third gage (6.4-T_6) did not become repeatable until after the first heating to 800° F. The response of this gage was also somewhat different from that of the other two gages. In all cases, the apparent strain due to temperature changes was small.

4.4 Transient Heating

The results of tests in which the temperature of the test strip to which the gage was attached was changed at about 60° F per second are shown in figures 23 through 29. Figures 23 through 25 show the response of one gage when subjected to three series of transient heating cycles. Each heating series consisted of five heating cycles from room temperature to a maximum temperature and back to room temperature. The maximum temperatures were about 600° F, 800° F, 1000° F, 1200° F, and 1500° F, in that order. Figures 23 and 24 show that the temperature coefficient of resistance of the installed gage was quite different after the first heating series. Figure 25 shows that a gage response is repeatable within close limits for the second and third heating series although the temperature coefficient of resistance is fairly large.

Figures 26 and 27 compare the response of two gages for the first and second heating series to maximum temperatures of 600° F and 1000° F. Although the curves for the two gages have the same general shape, the agreement between the two gages is not comparable to the repetition of one gage for two test runs as shown in figures 28 and 29. The curves of figures 28 and 29 show the maximum spread for ten heating cycles to 800° F followed by ten heating cycles to 1500° F for two gages. Except for the response during the first heating to 1500° F, the behavior of each gage was repeatable within close limits. The different behavior during the first heating to 1500° F was expected from the results shown in figure 24.

4.5 High Strains

The results of tests in which gages were subjected to tensile strains greater than those used for gage factor determination are shown in figure 30. The gage factor values used to determine the strain indicated by the resistance gage, ϵ_{ind}, were obtained from the average of values obtained for tensile strains at room temperature, table 2, and the average variation of gage factor with temperature, figure 7. The actual strain, ϵ, was measured with an optical strain gage.

The differences between the actual strain and the strain indicated by the resistance gages were only slightly greater than 5 percent of the indicated strain at any point for gages tested at room temperature. These differences were less than 5 percent of the indicated strain for gages tested at 600° F. Errors of this magnitude would be expected since the gage factor tolerance given by the manufacturer is ± 5 percent.

The gages tested at 600° F were subjected to strains slightly more than 0.01. The gages tested at room temperature were subjected to strains of about 0.02 and 0.015. All tests were discontinued before failure of the resistance gage occurred. Errors for gages strained beyond the values

shown in figure 30 did not exceed the maximum shown for that gage in figure 30.

The results of similar tests on four other gages are not given in this report since a possible error in experimental procedure makes the validity of the results obtained doubtful. The maximum strain levels for the tests of these gages were about the same as for the gages reported except for one gage which was subjected to a strain greater than 0.037 at room temperature. None of these gages failed during the tests.

Two of the gages, 6.4-H_5 and 6.4-H_7, were attached with standard welder attachments. The other two gages, 6.4-H_6 and 6.4-H_8, were attached with the Rollectrode attachment. It is felt that the differences shown in figure 30 are not due to differences in the method of attachment.

4.6 Resistance to Ground

It has been reported that ceramic type cements do not follow Ohm's law and that polarization effects are encountered, at least at higher temperatures.[9] It is expected that this would also be true for the insulation which forms a part of the gages tested for this report. The resistance values shown in figure 31 should therefore be considered as qualitative values only. The values were obtained during drift tests with a Triplett vacuum tube volt-ohm meter, Model 650, using the scale range marked x 1 megΩ. The common terminal of the instrument was connected to the test strip. The values shown in figure 31 are average values for two gages. The readings were taken within a few minutes after the test strip had reached the test temperature.

4.7 Gages Destroyed

During the course of this evaluation, four gages were destroyed before the intended information was obtained. Leads of two of these gages were broken while attaching the external lead wires, one gage wire broke just inside the metal tubing during the first transient heating cycle, and a lead of the other gage was accidently cut with the Rollectrode while attaching the gage to the test strip. The first three of these failures were probably due to bending of the gage leads. This indicates that these leads are fragile and must be handled carefully. The manufacturer warns against excessive bending of the leads.

5. CONCLUSIONS

The data obtained from the evaluation tests covered by this report indicate that:

(1) Gage factor values for gage type SS-E-4D-A can be expected to be within the manufacturer's stated limits at room temperature. The decrease of gage factor with increasing temperature is approximately linear, at least up to 800° F, and repeatable from gage to gage.

(2) These gages may be useful for static strain measurements at temperatures as high as 700° F. At temperatures of 800° F and higher, the drift characteristics will probably preclude their use for many static measurements.

(3) These gages have a very low temperature coefficient of resistance when attached to stainless steel provided the gages are not heated to temperatures above about 850° F. The temperature coefficient becomes very repeatable after the first temperature cycle. If the gages are heated to about 1500° F, the temperature coefficient becomes quite high, but it is repeatable.

(4) The gages will indicate tensile strains as high as 0.02 with an accuracy of about 5 percent. The gages will withstand very high strains without failure.

(5) The gages are very easily installed and require no thermal curing provided installation can be made by spotwelding.

(6) The agreement between the predicted and actual strains indicated by the resistance gages for high strains at 600° F confirms the validity of the method used to determine the variation of gage factor with temperature.

Washington, D. C.

August 1959

6. REFERENCES

(1) R. L. Bloss and C. H. Melton, An Evaluation of Two Types of Resistance Strain Gages at Temperatures up to 600° F, NBS Report No. 4676, May 1956 (ASTIA No. AD 94696).

(2) R. L. Bloss and C. H. Melton, An Evaluation of One Type of Resistance Strain Gage at Temperatures up to 600° F, NBS Report No. 4747, July 1956 (ASTIA No. AD 101079).

(3) R. L. Bloss and C. H. Melton, An Evaluation of Two Types of Resistance Strain Gages at Temperatures up to 600° F, NBS Report No. 4843, September 1956 (ASTIA No. AD 107662).

(4) R. L. Bloss and C. H. Melton, An Evaluation of Strain Gages Designed for Use at Elevated Temperatures -- Preliminary Tests for Temperatures up to 1000° F, NBS Report No. 5286, May 1957 (ASTIA No. AD 135050).

(5) R. L. Bloss and C. H. Melton, Evaluation of Resistance Strain Gages at Elevated Temperatures (Progress Report No. 5), NBS Report No. 6117, August 1958 (ASTIA No. AD 202419).

(6) R. L. Bloss, C. H. Melton, and M. L. Seman, Evaluation of Resistance Strain Gages at Elevated Temperatures (Progress Report No. 6), NBS Report No. 6245, December 1958, (ASTIA No. AD 211391).

(7) R. L. Bloss, C. H. Melton, and J. T. Trumbo, Evaluation of Resistance Strain Gages at Elevated Temperatures. (Progress Report No. 7) NBS Report No. 6395, April 1959.

(8) R. L. Bloss, A Facility for the Evaluation of Resistance Strain Gages at Elevated Temperatures, Symposium on Elevated Temperature Strain Gages, ASTM Special Technical Publication No. 230, pp. 57-66.

(9) J. W. Pitts, E. Buzzard, and D. G. Moore, Resistance Measurement of Ceramic-Type Strain-Gage Cements, Symposium on Elevated Temperature Strain Gages, ASTM Special Technical Publication No. 230, pp 67-75.

Table 1 - Number of Gages Subjected to Tests

Type of Tests	Number of gages tested
Gage factor	3
Gage factor variation	12*
Drift	2
Temperature sensitivity	5**
Transient heating	5**
High strain	4

*Three sets of four gages.

**Three gages were subjected to transient heating tests after temperature sensitivity tests were completed.

Table 2 - Gage Factor Values at About 75° F

Gage No.	Run No.	Gage Factor Values					
		Tension			Compression		
		K_u	K_d	$\bar{K}$	K_u	K_d	$\bar{K}$
	1	1.842	1.845	1.843	1.865	1.864	1.864
6.4-A_1	2	1.854	1.844	1.849	1.874	1.878	1.876
	3	1.843	1.848	1.846	1.876	1.878	1.877
	Average	1.846	1.846	1.846	1.872	1.873	1.872
	1	1.780	1.833	1.807	1.831	1.834	1.832
6.4-A_2	2	1.788	1.851	1.819	1.825	1.830	1.828
	3	1.806	1.823	1.814	1.831	1.844	1.837
	Average	1.791	1.836	1.813	1.829	1.836	1.832
	1	1.783	1.797	1.790	1.773	1.823	1.798
6.4-A_3	2	1.775	1.786	1.780	1.813	1.826	1.819
	3	1.777	1.786	1.781	1.807	1.819	1.813
	Average	1.778	1.790	1.784	1.798	1.823	1.810
Grand Average		1.805	1.824	1.814	1.833	1.844	1.838

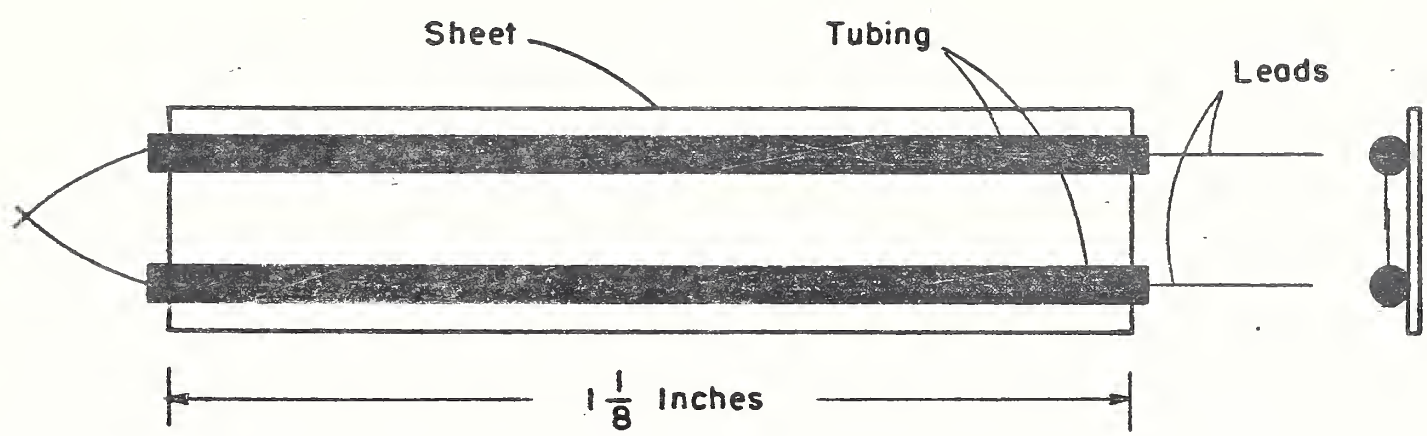

Fig. 1 Gage configuration

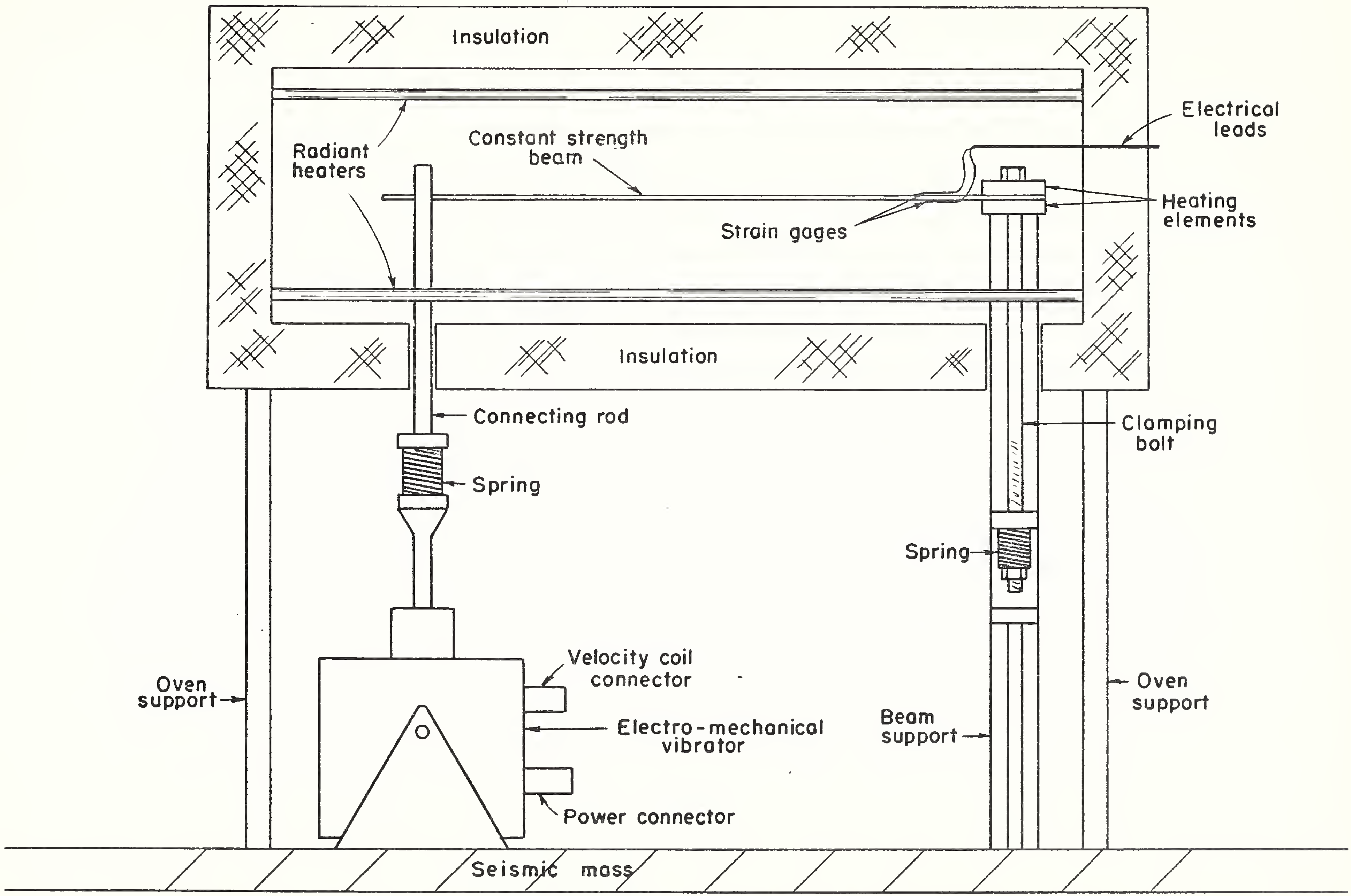

Fig. 2 Equipment for determining variation of gage factor with temperature.

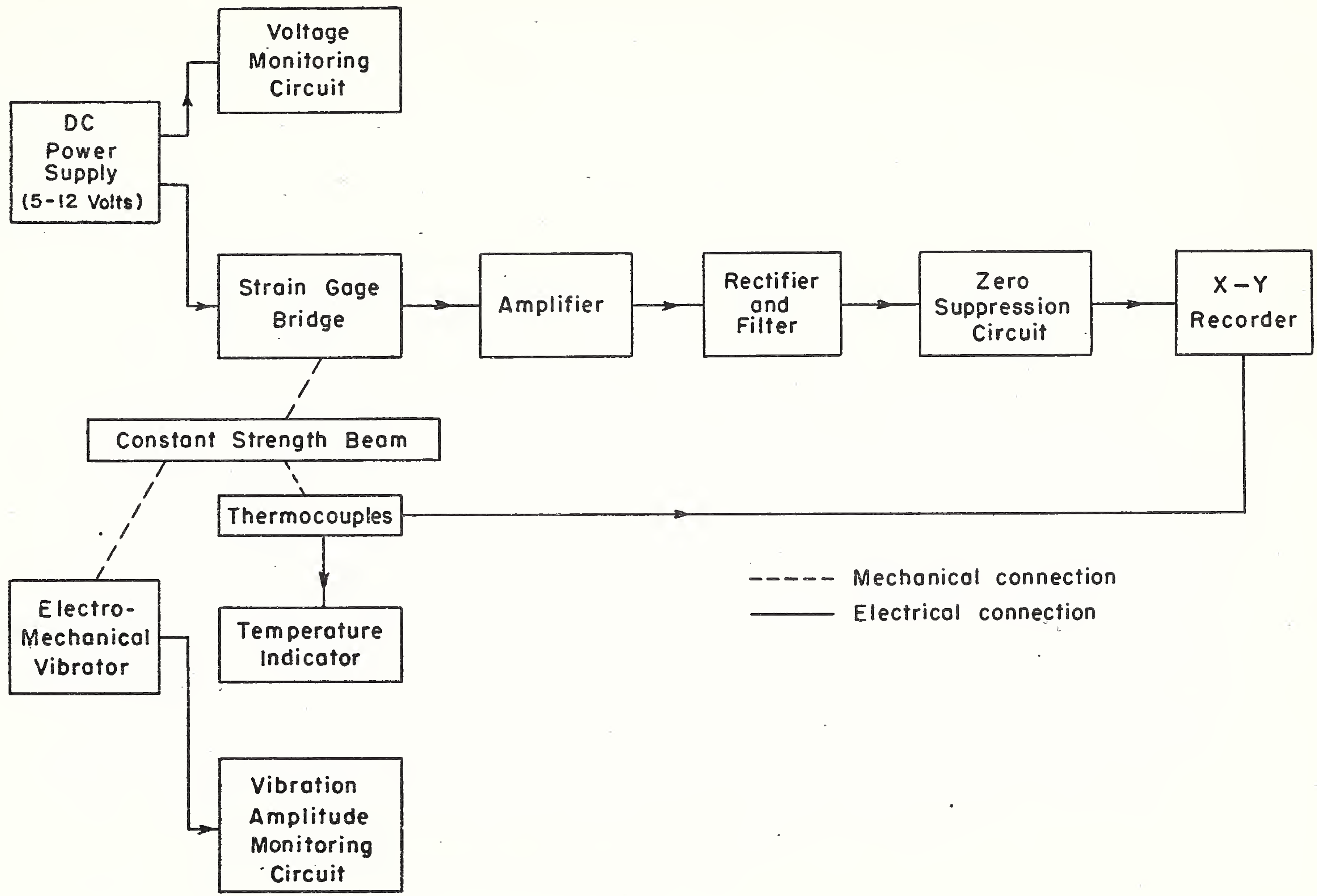

Fig. 3 Equipment for determining variation of gage factor with temperature

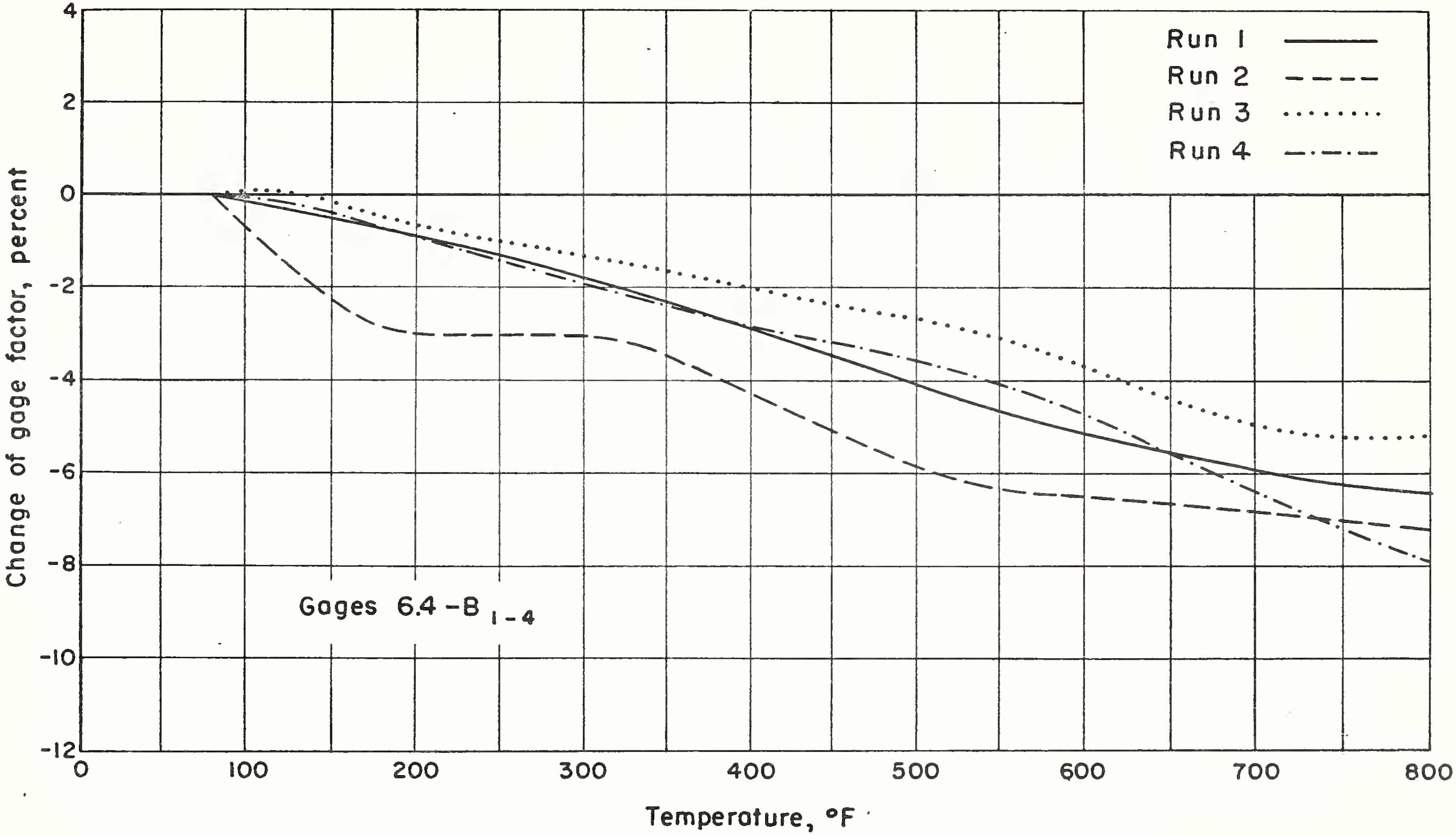

Fig. 4 Variation of gage factor with temperature

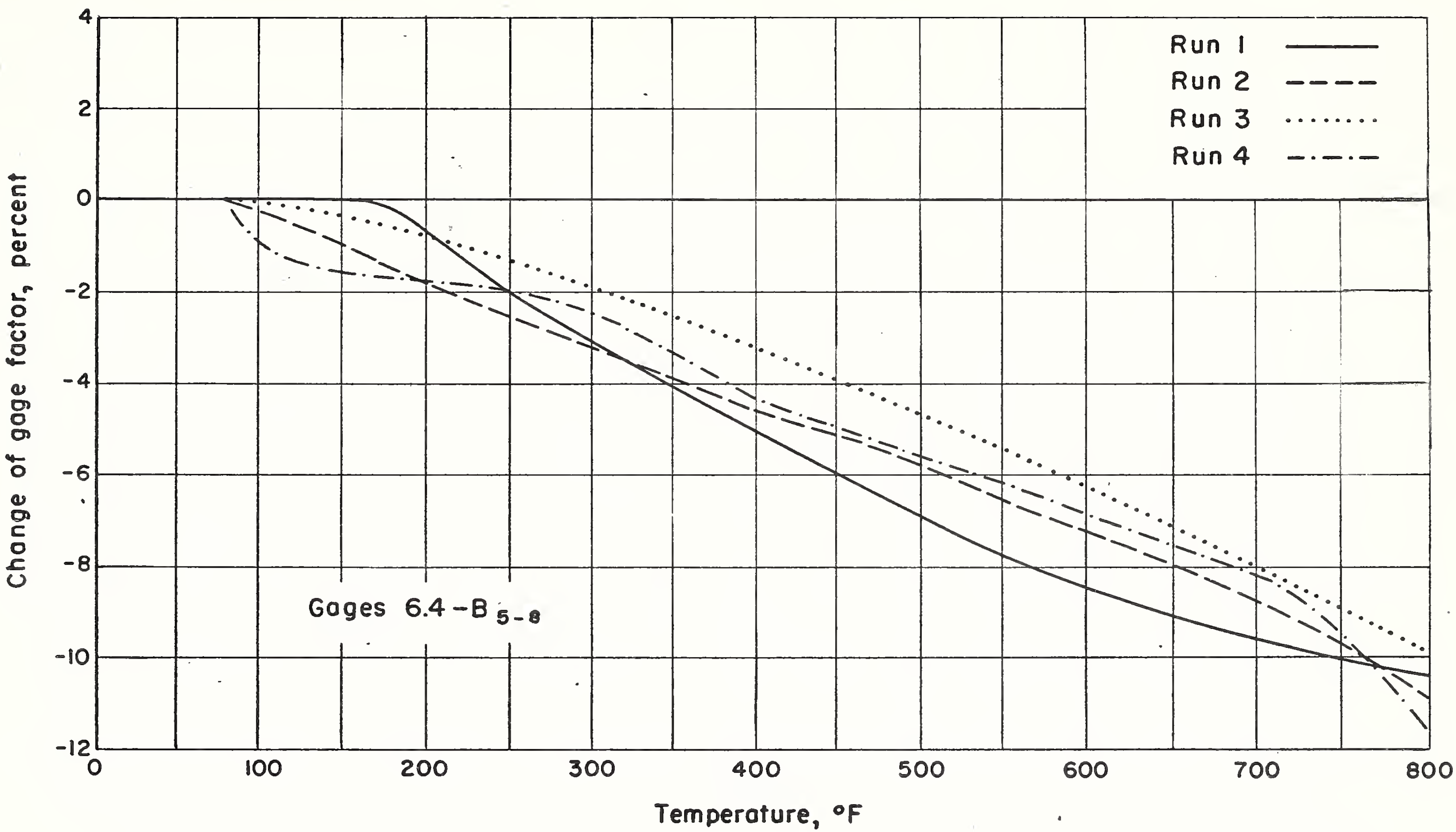

Fig. 5 Variation of gage factor with temperature

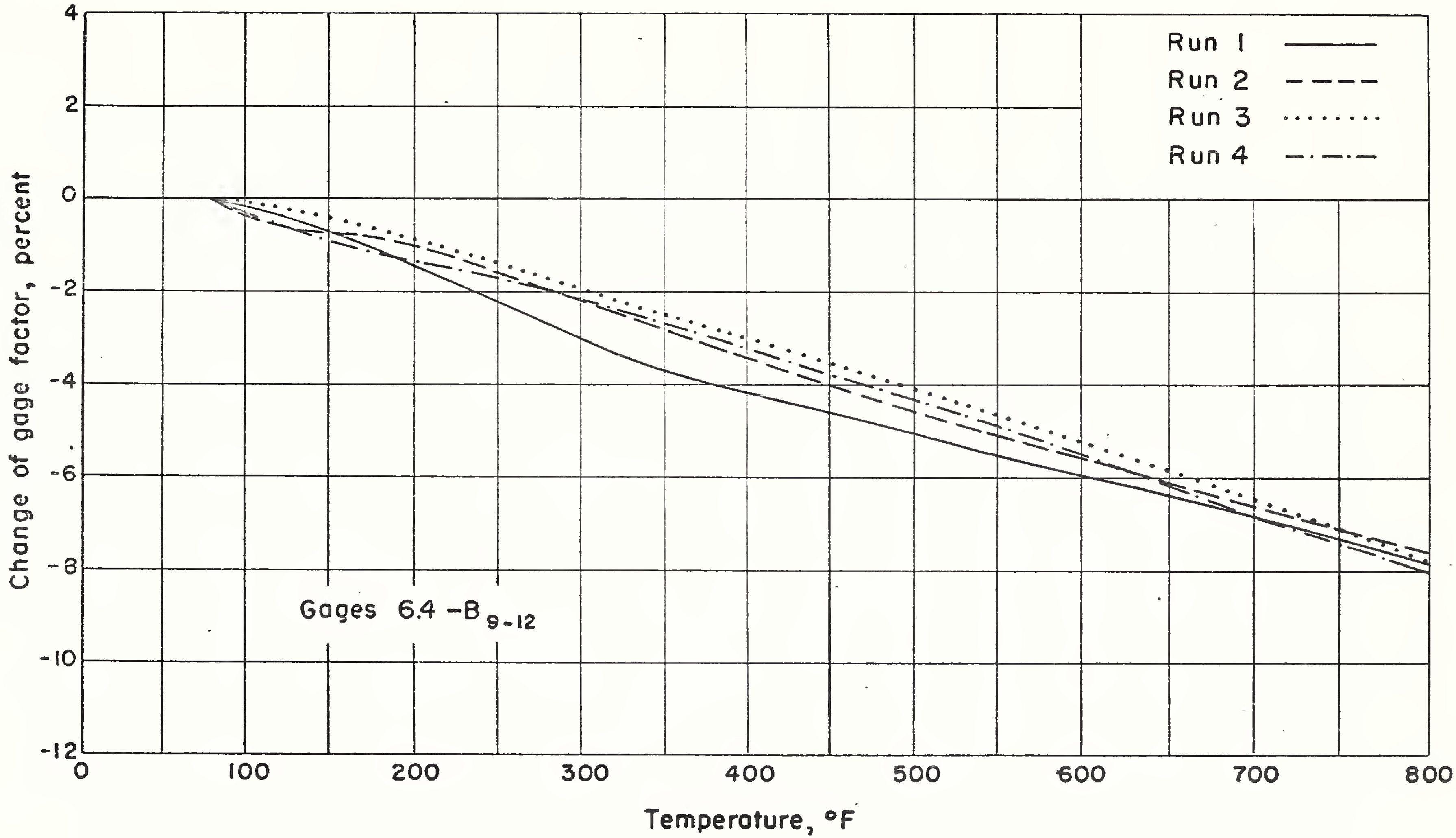

Fig. 6 Variation of gage factor with temperature

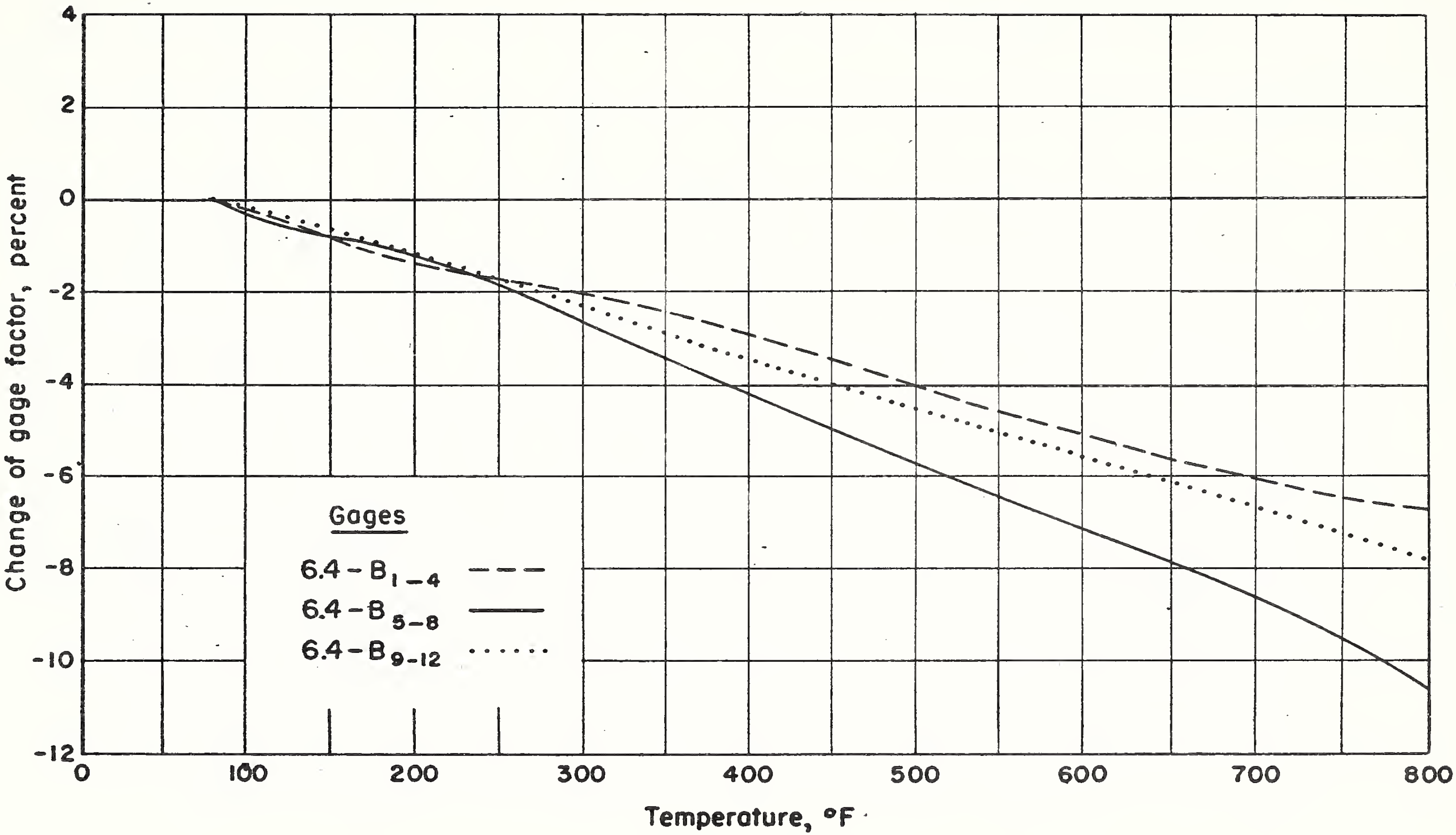

Fig. 7 Average variation of gage factor with temperature for four tests

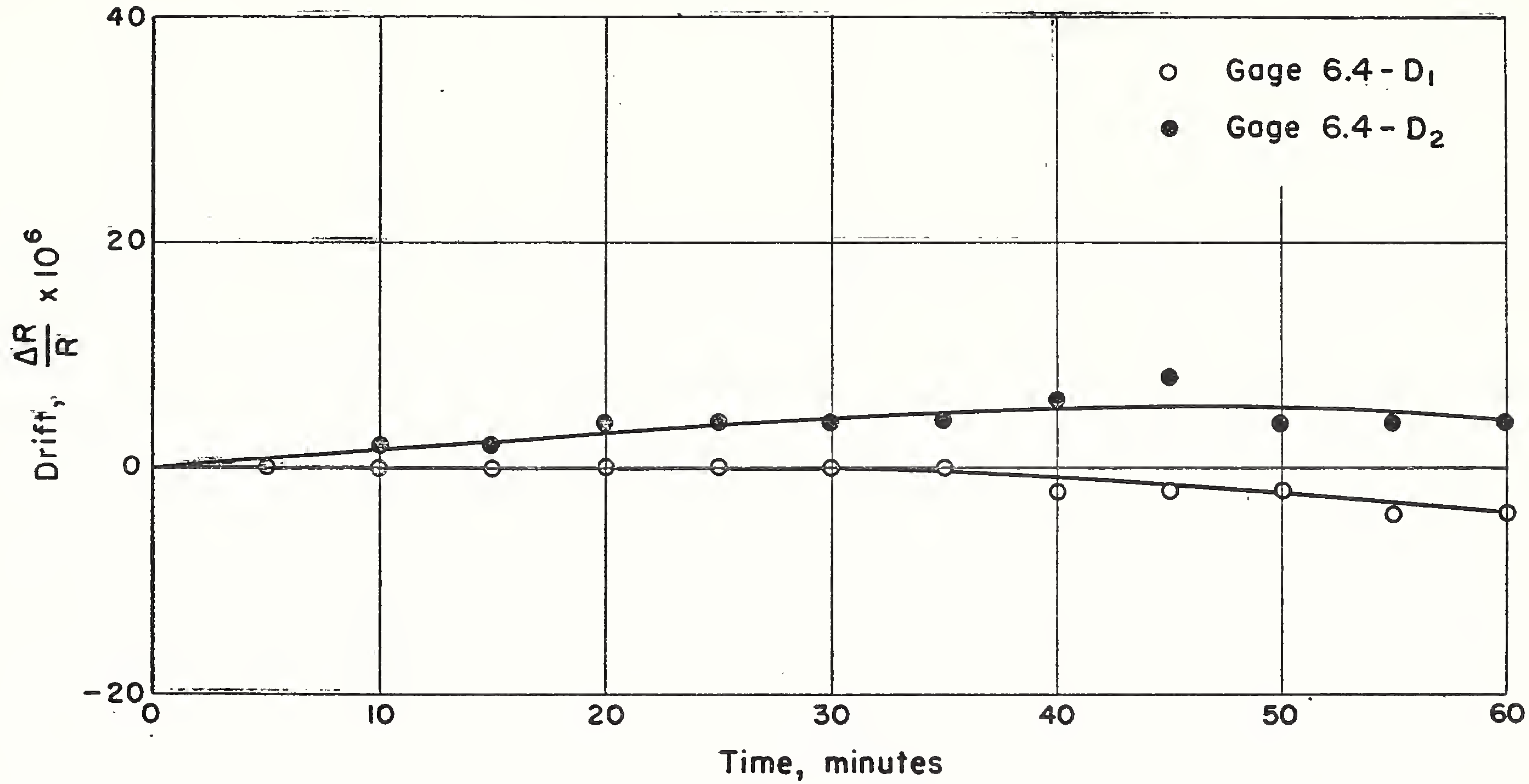

Fig. 8 Drift behavior at 300° F

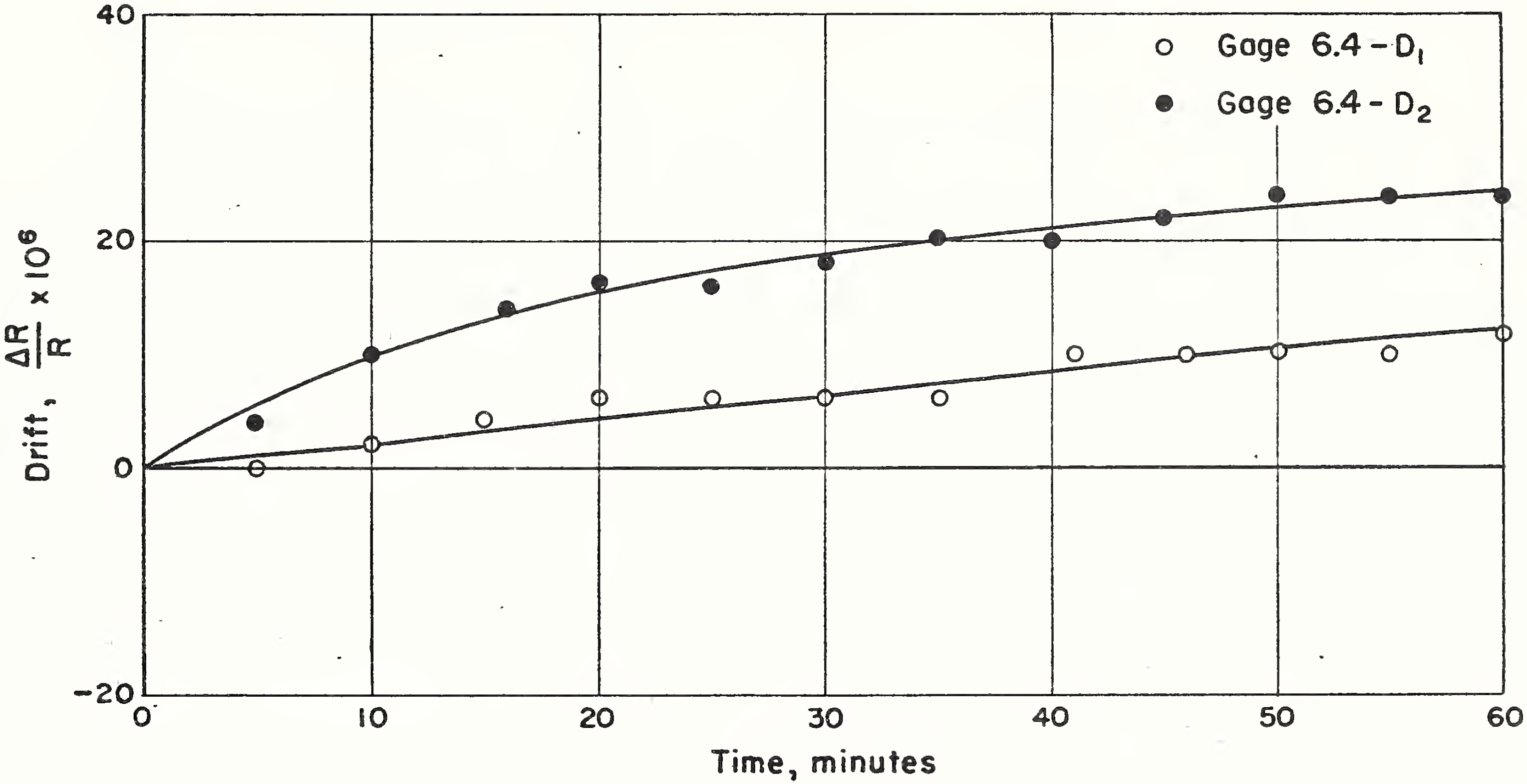

Fig. 9 Drift behavior at 400° F

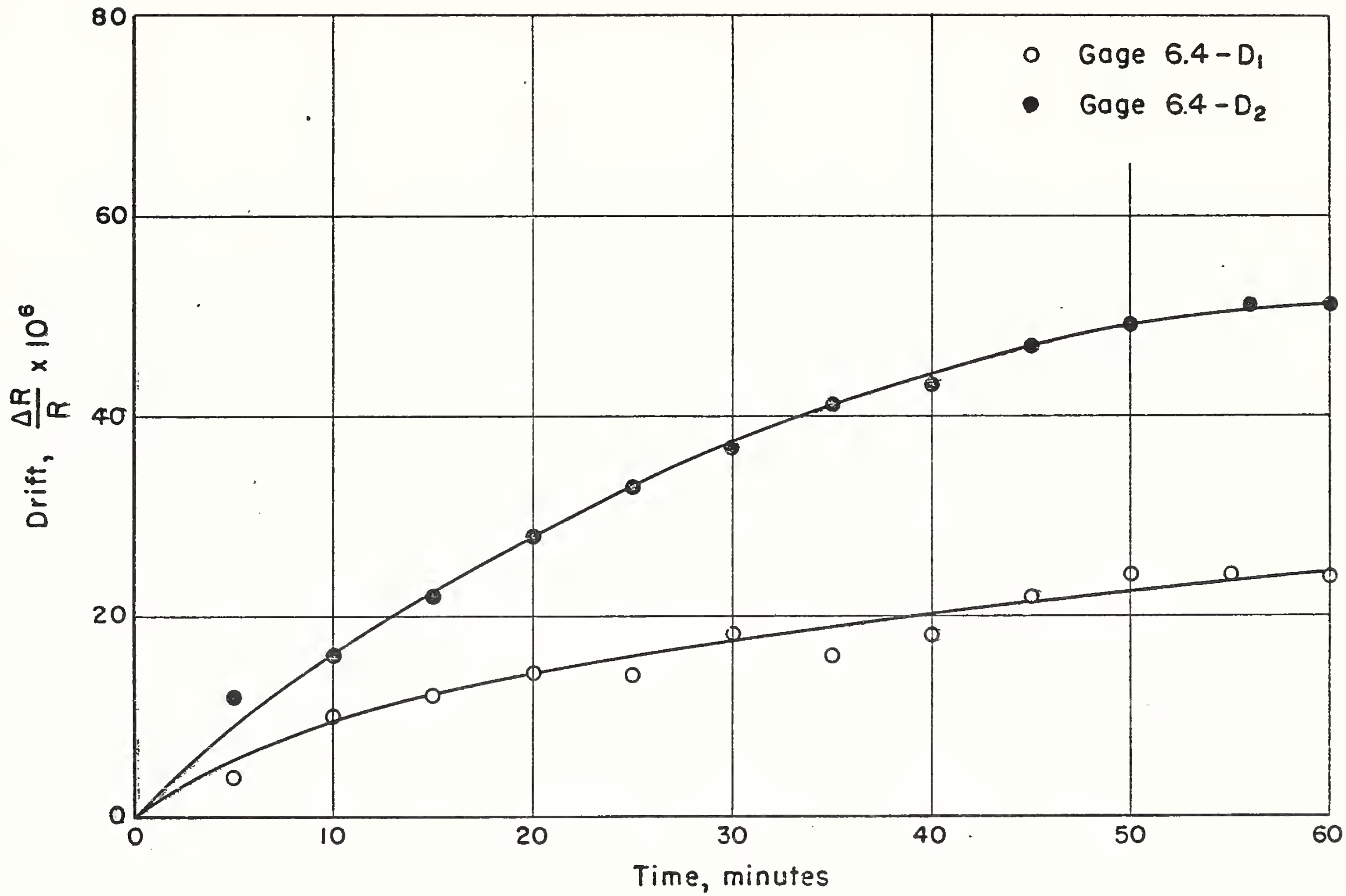

Fig. 10 Drift behavior at 500° F

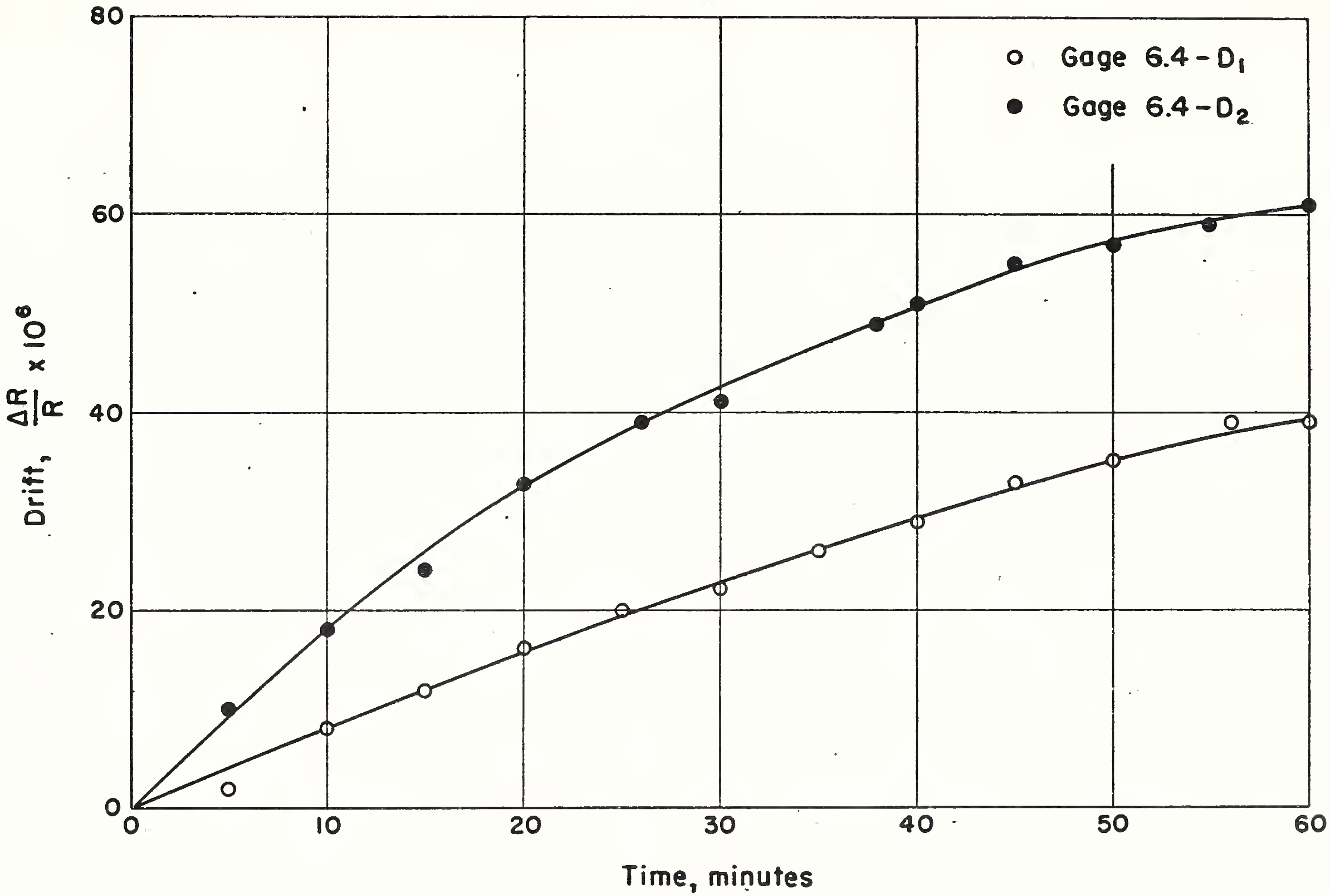

Fig. 11 Drift behavior at 600° F

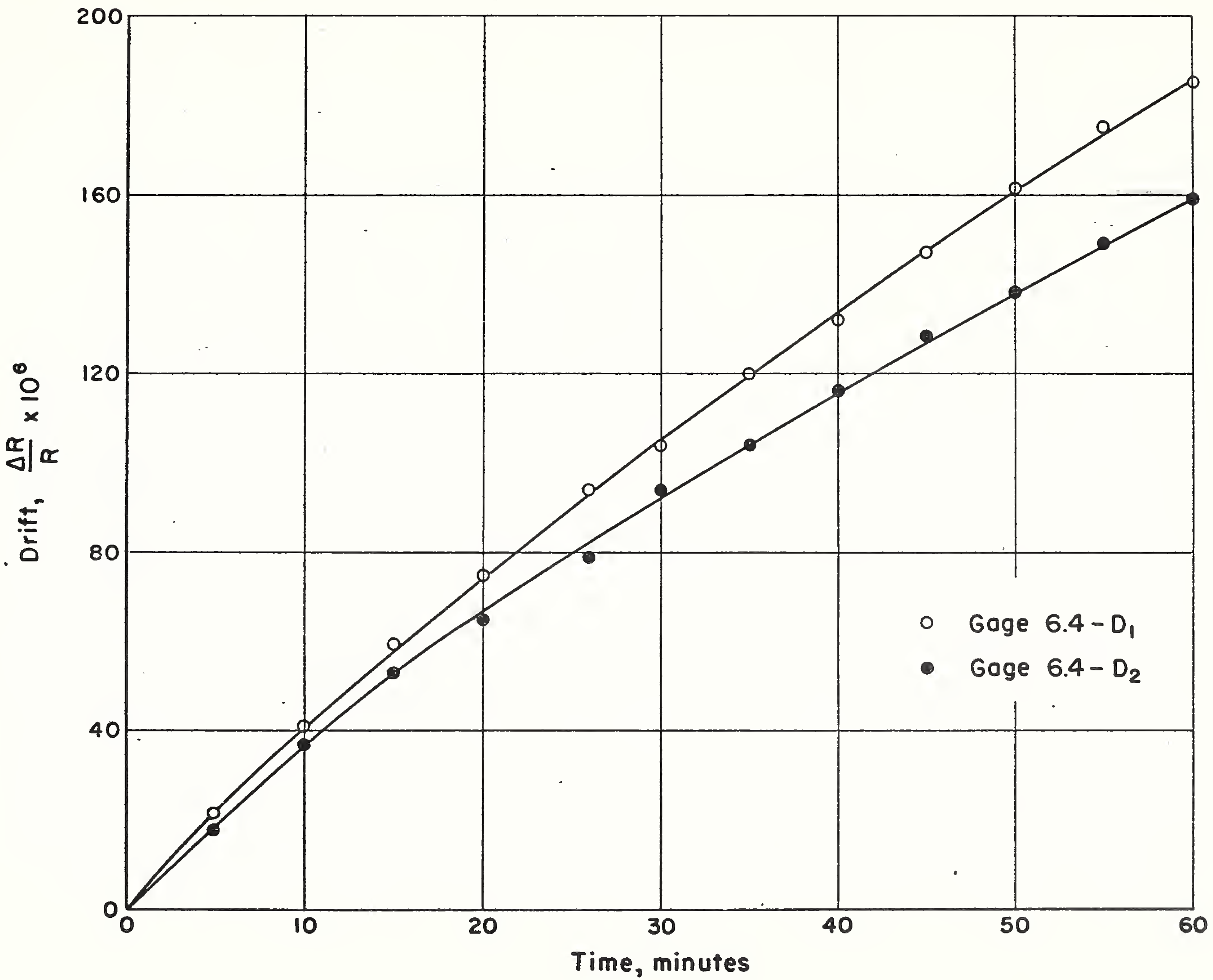

Fig. 12 Drift behavior at 700°F

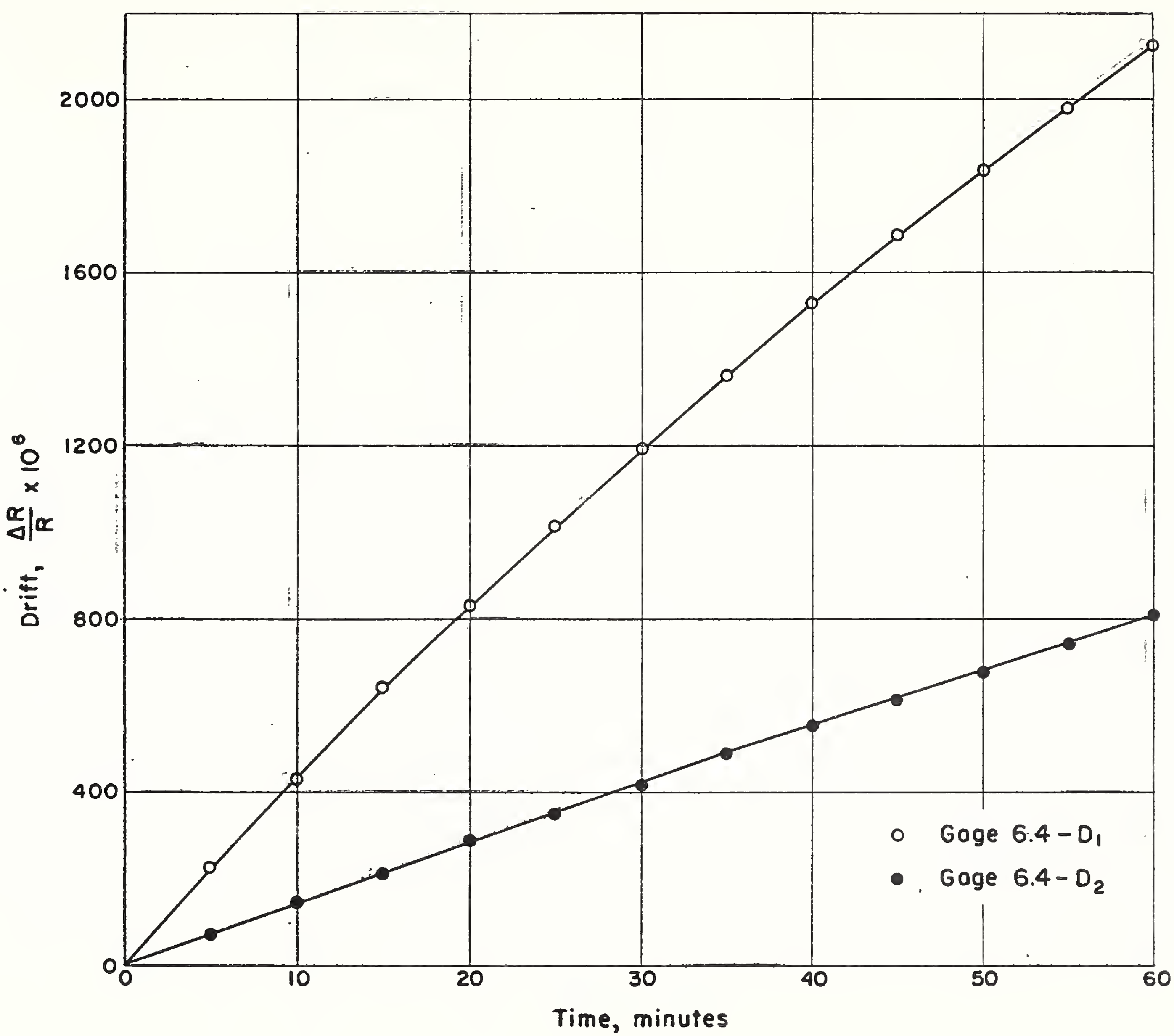

Fig. 13 Drift behavior at 800° F

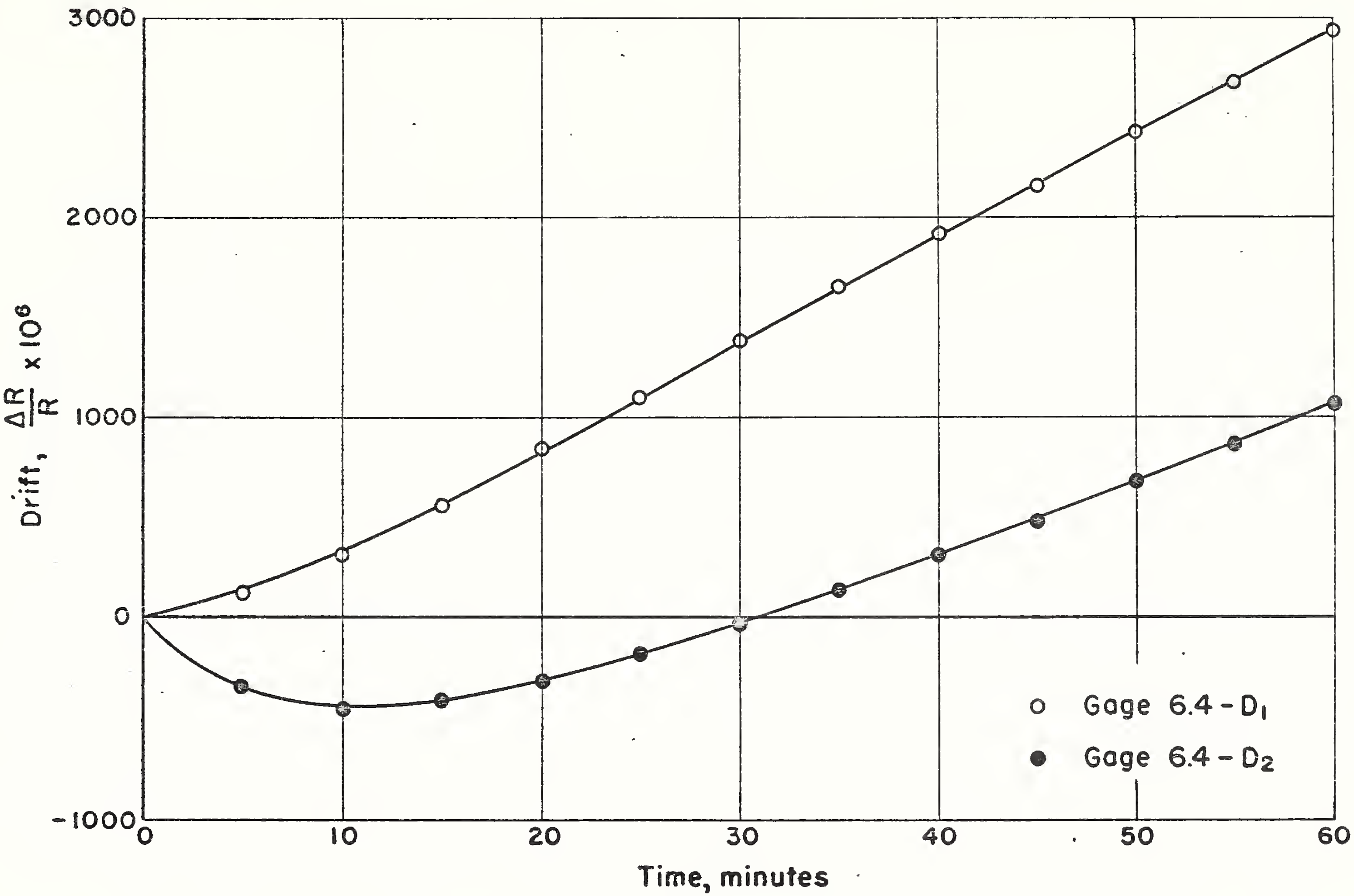

Fig. 14 Drift behavior at 900° F

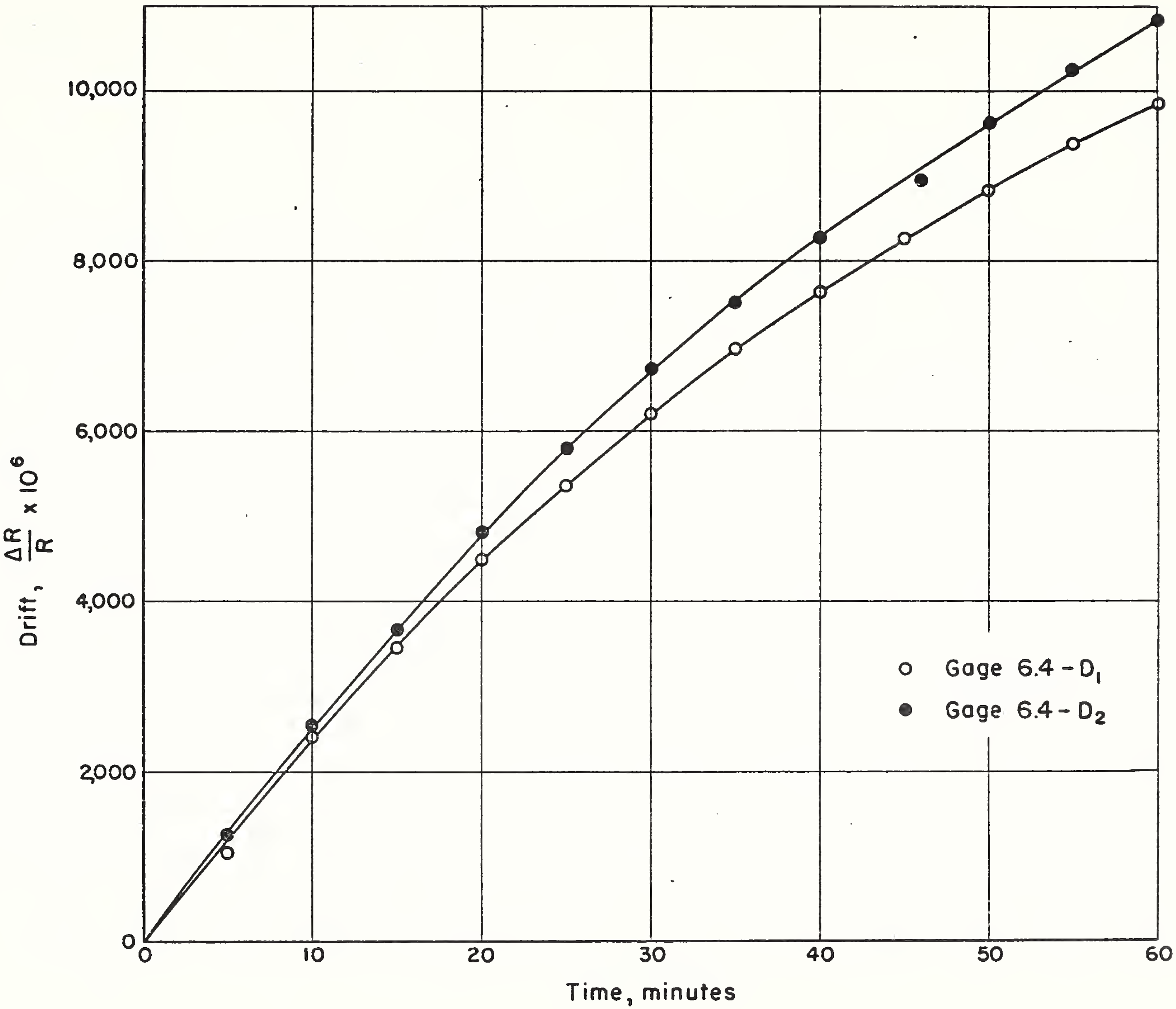

Fig. 15 Drift behavior at 1000° F

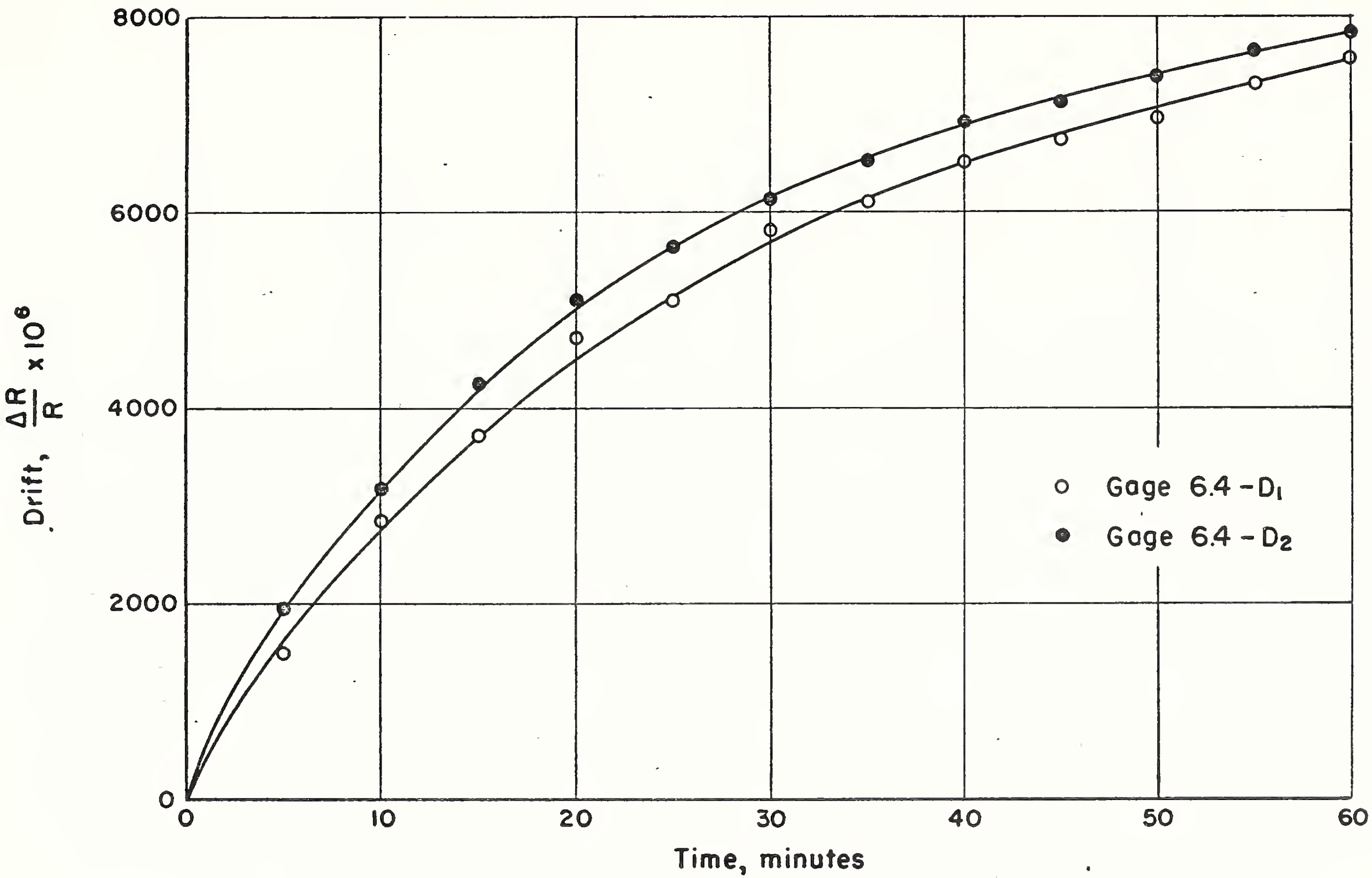

Fig. 16 Drift behavior at 1100° F

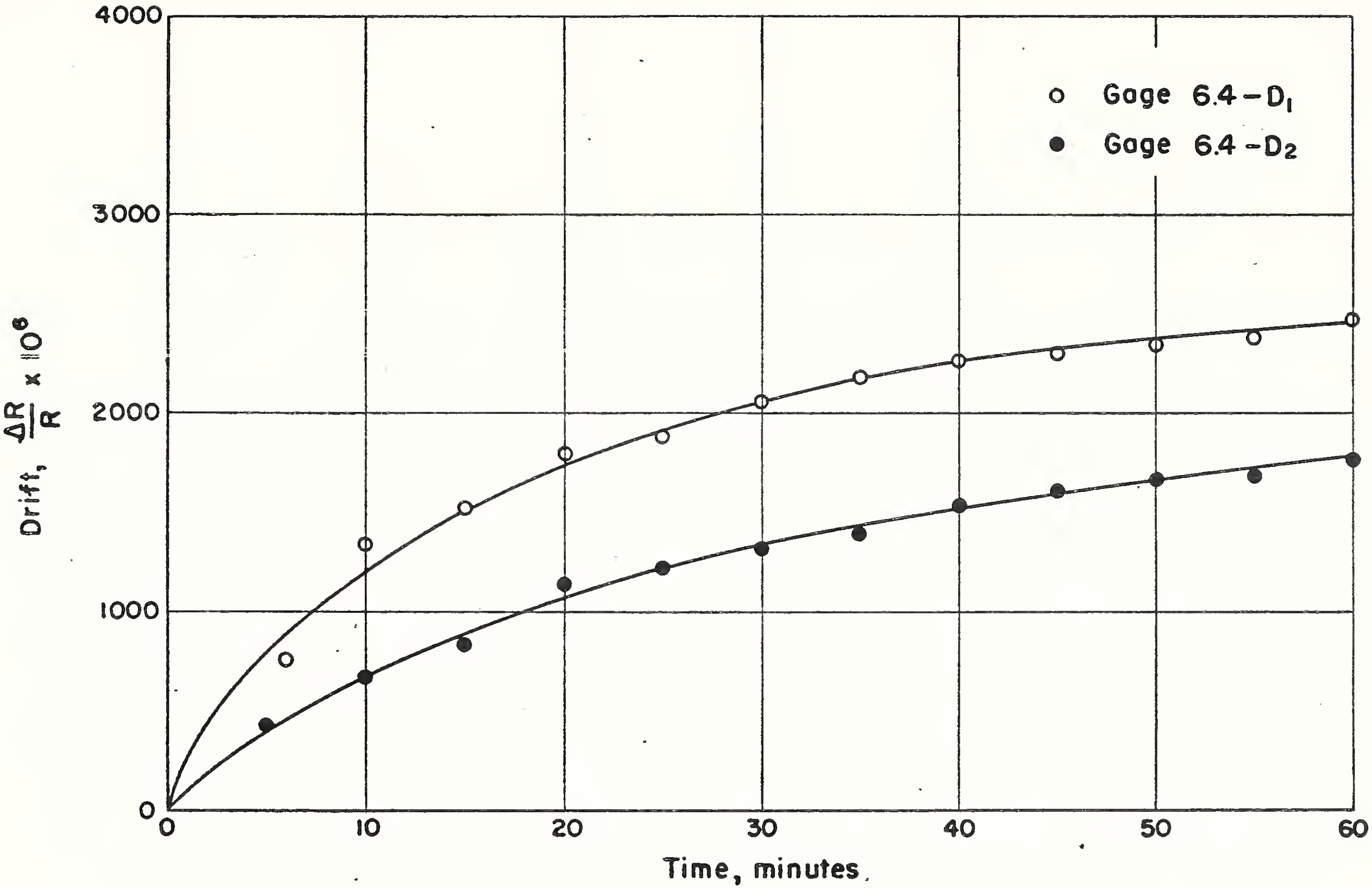

Fig. 17 Drift behavior at 1200° F

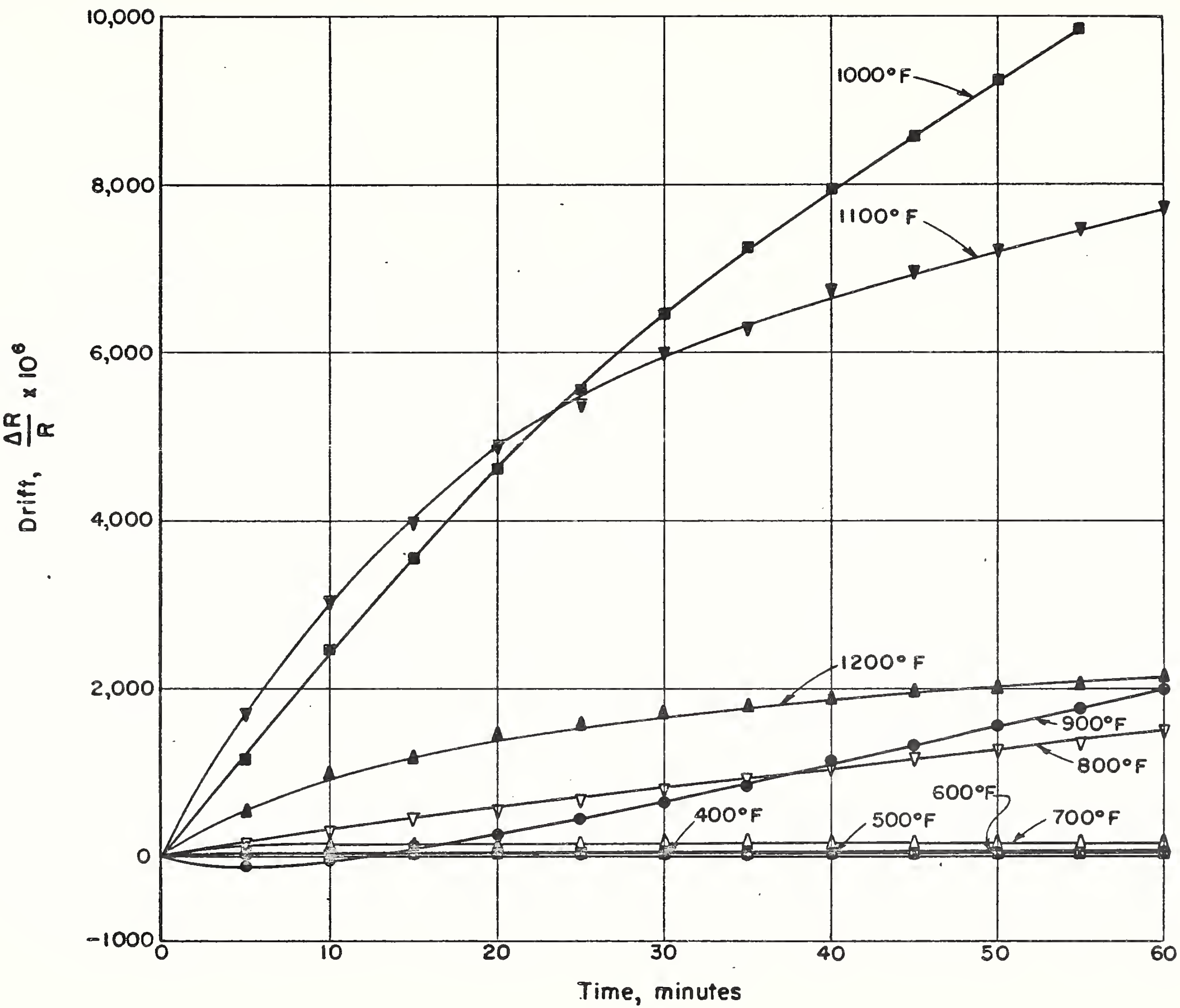

Fig. 18 Average drift of two gages ($6.4-D_1$ and $6.4-D_2$)

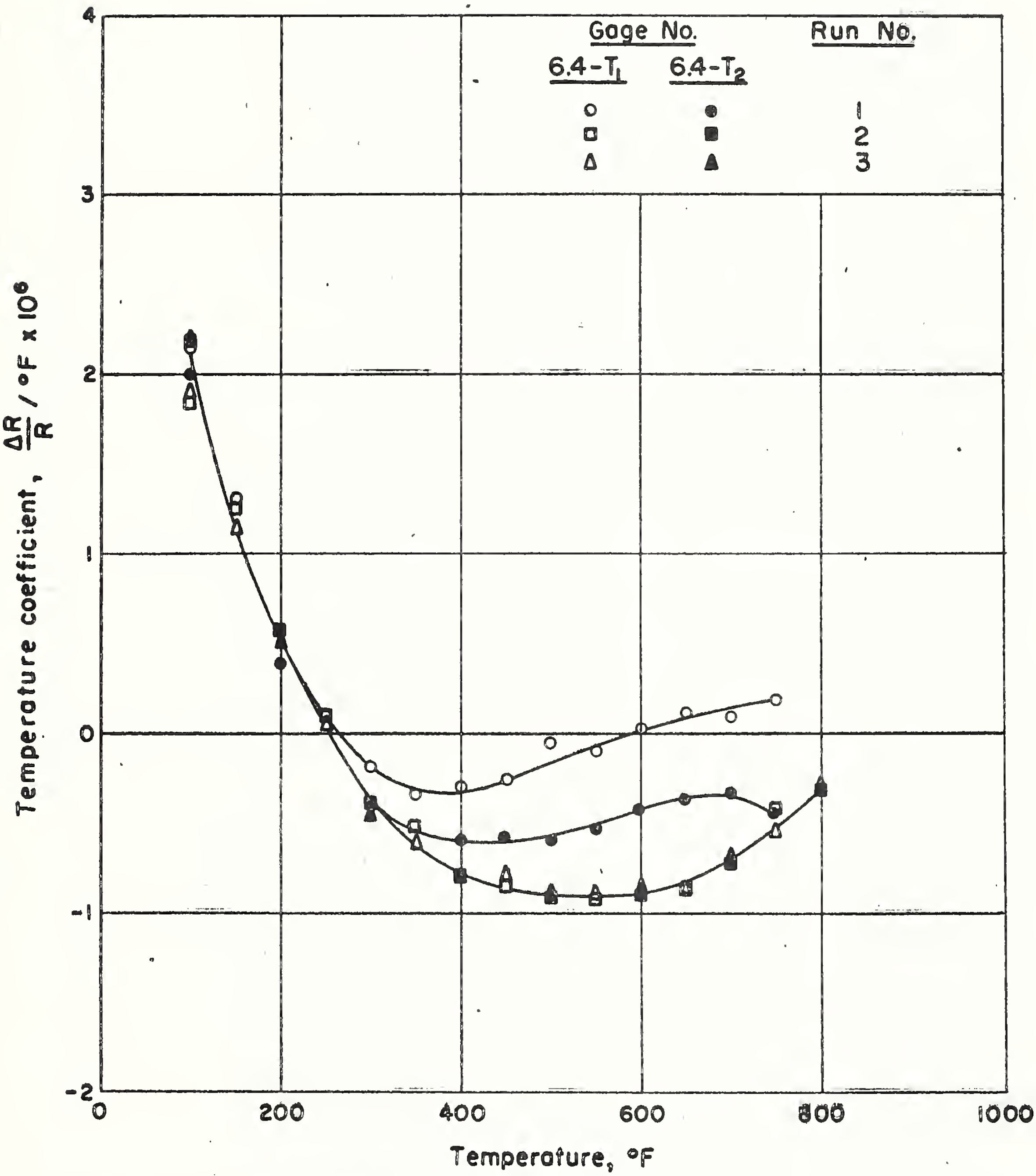

Fig. 19 Temperature coefficient of two gages

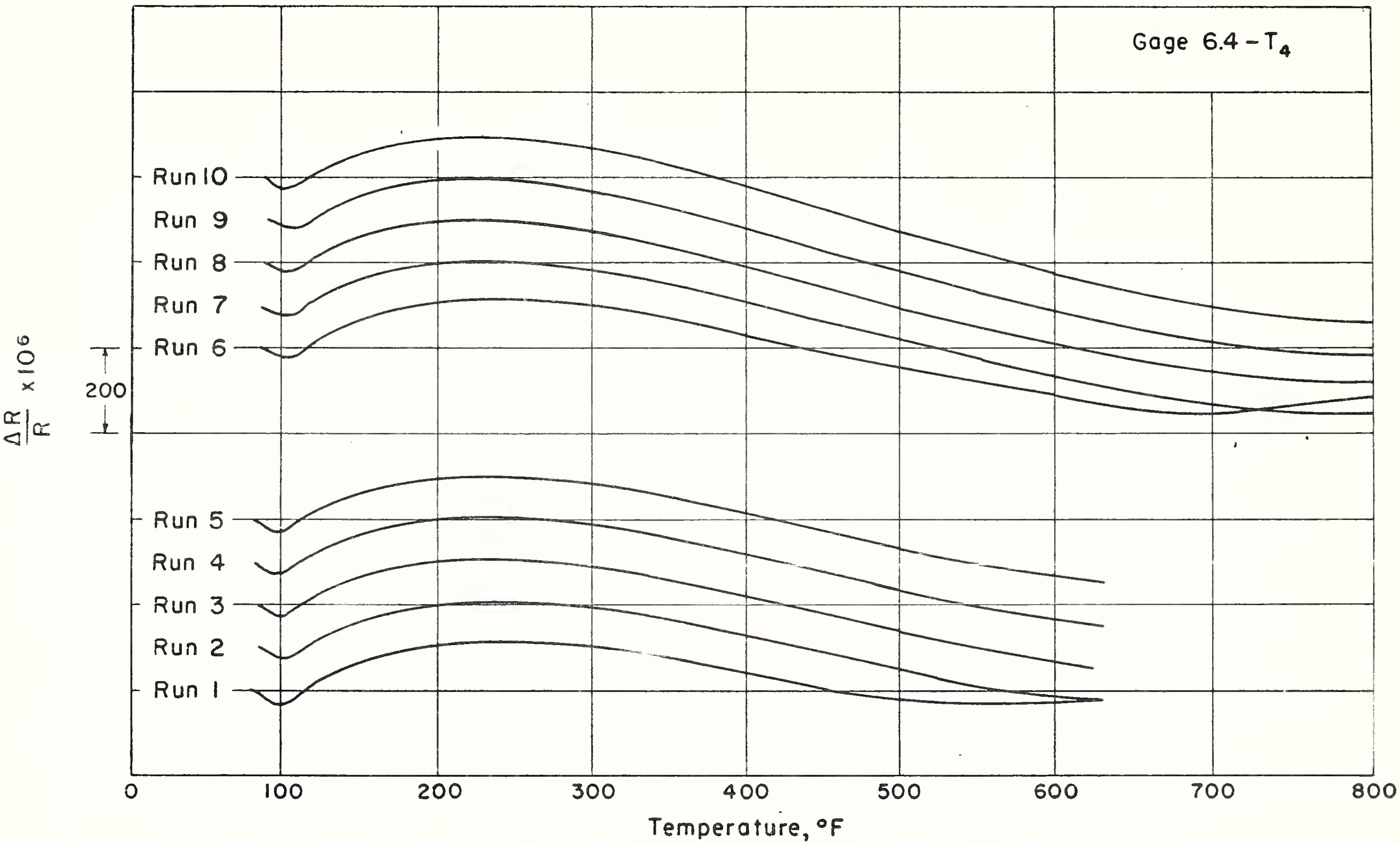

Fig. 20 Variation of gage resistance with increasing temperature

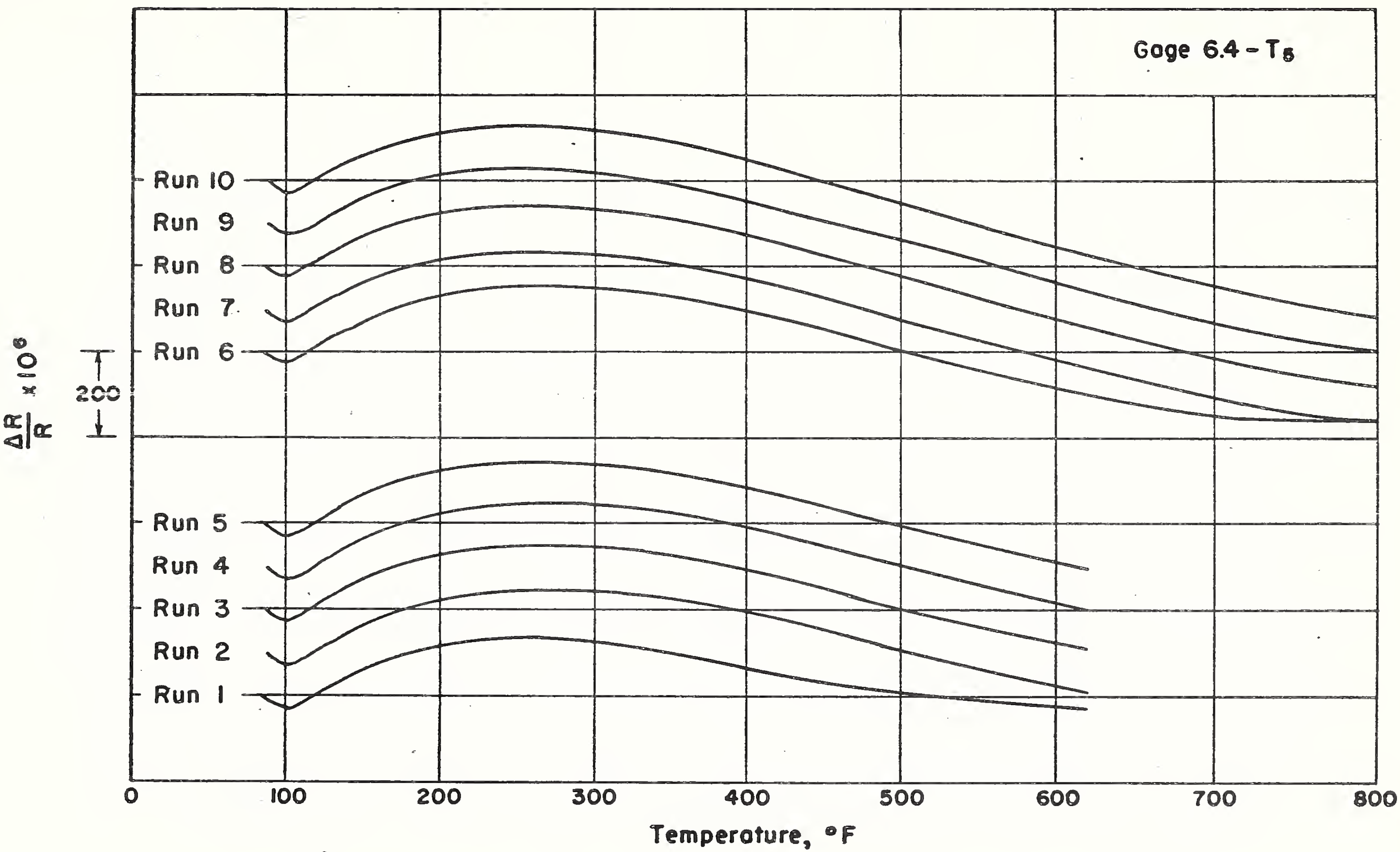

Fig. 21 Variation of gage resistance with increasing temperature

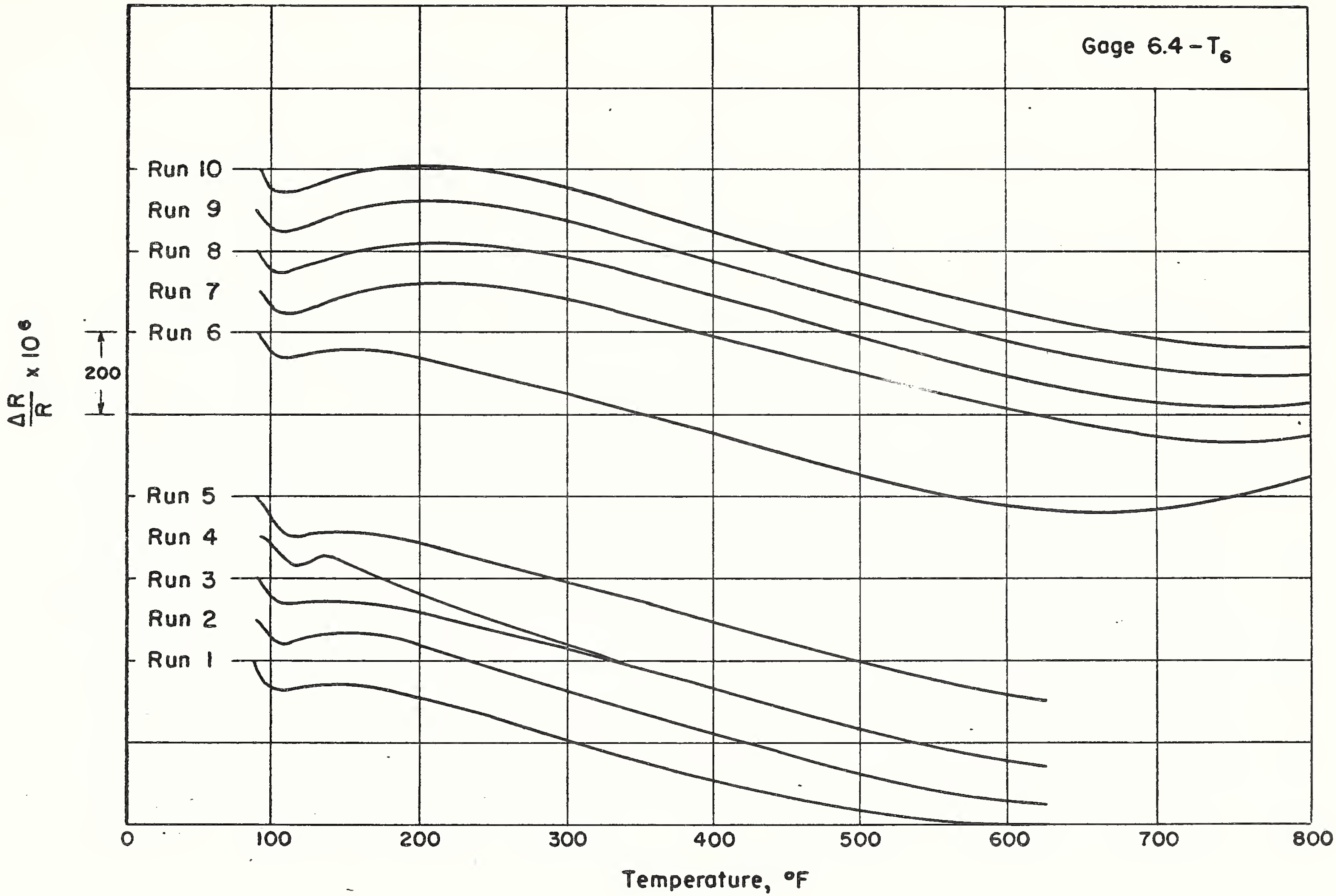

Fig. 22 Variation of gage resistance with increasing temperature

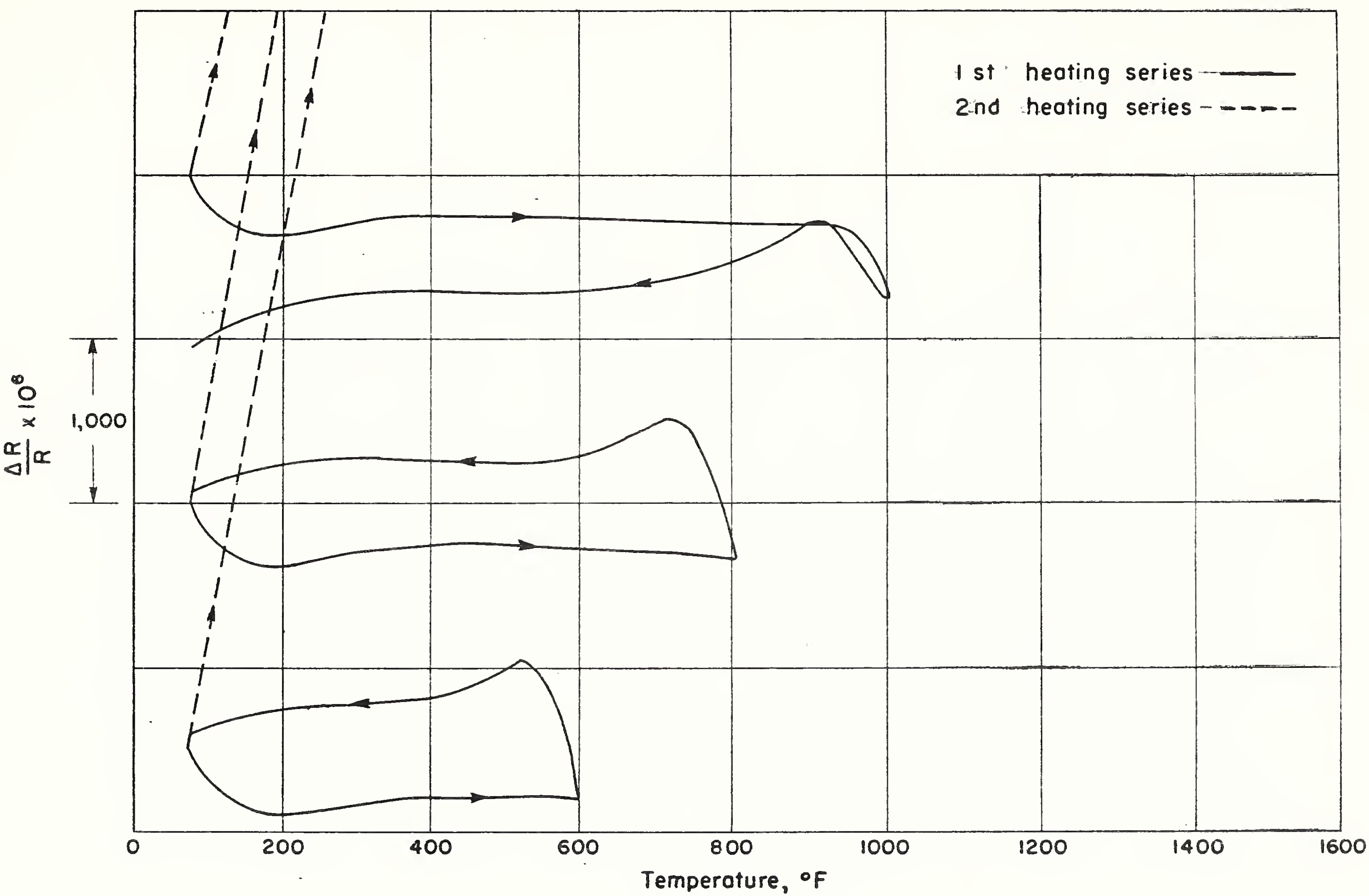

Fig. 23 Gage response with transient heating.

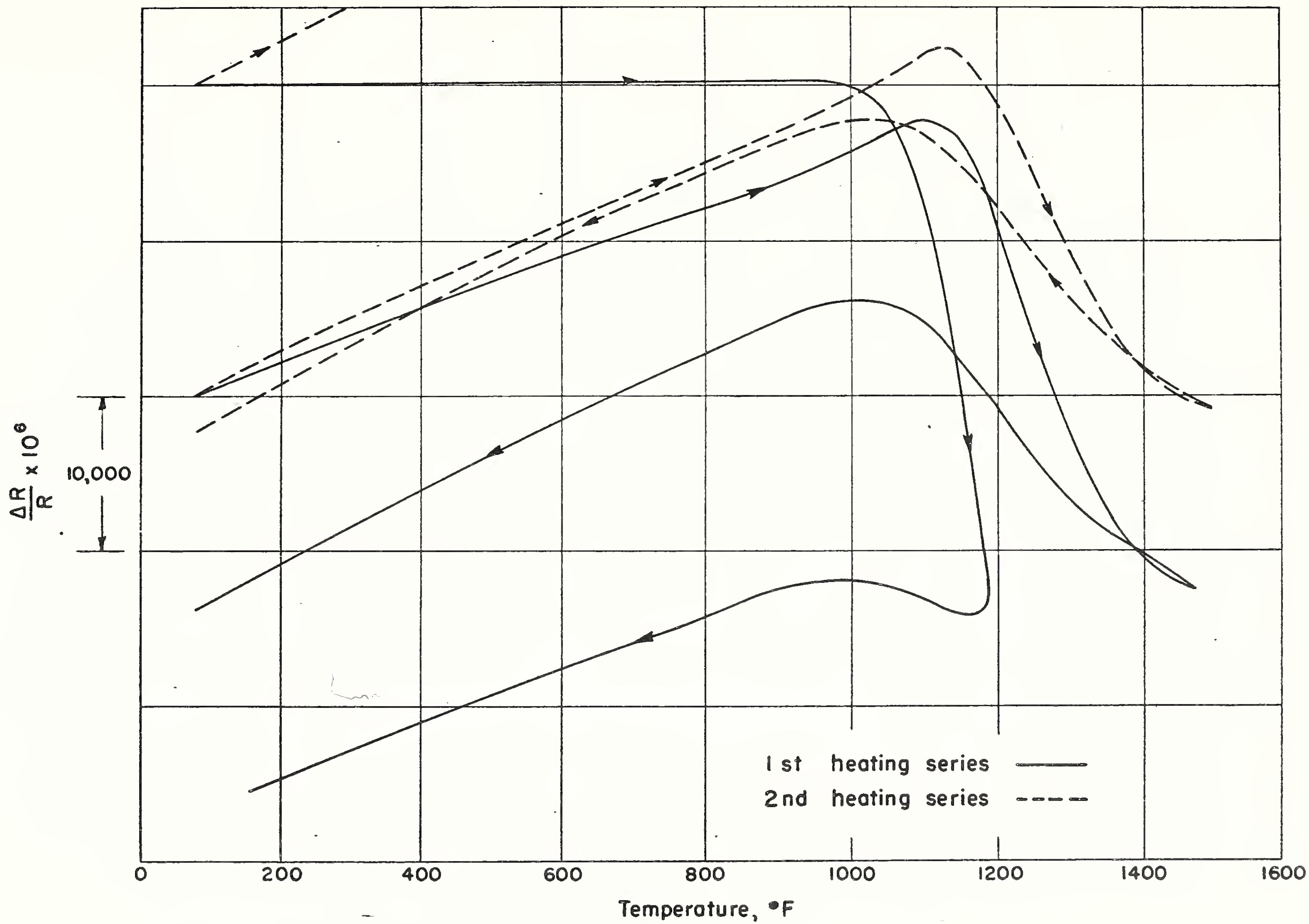

Fig. 24 Gage response with transient heating.

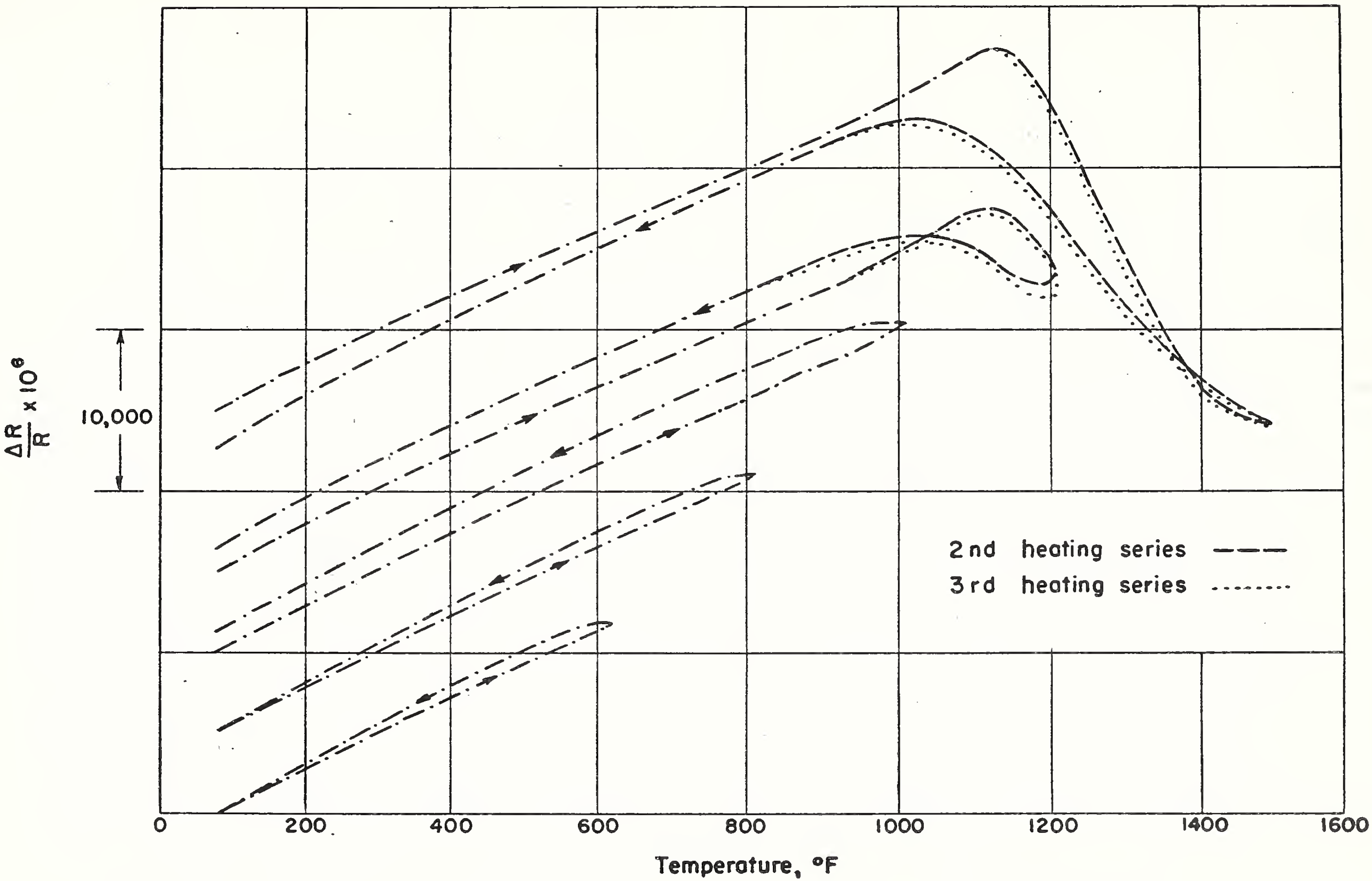

Fig. 25 Gage response with transient heating.

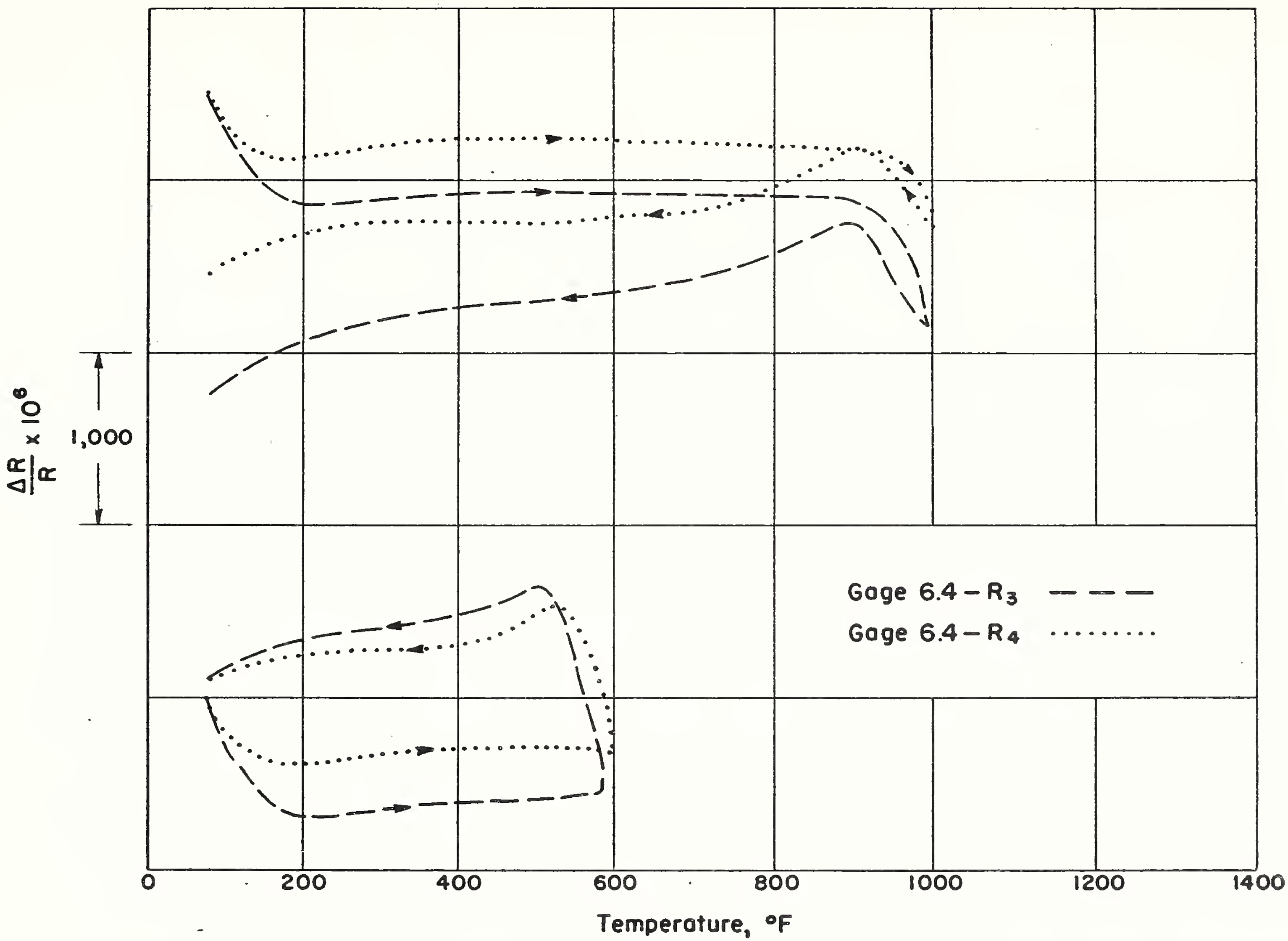

Fig. 26 Response of two gages with transient heating. 1st heating series

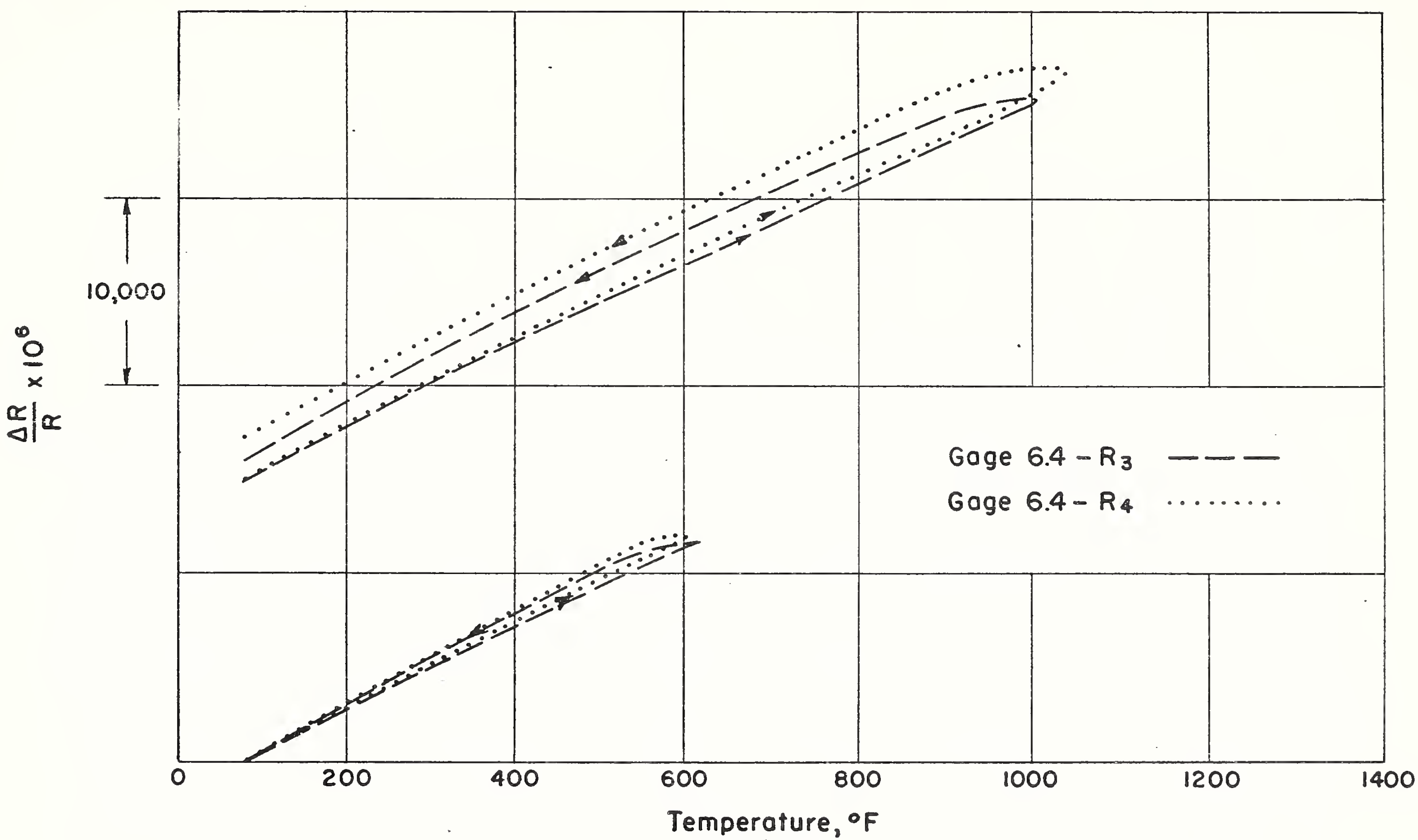

Fig. 27 Response of two gages with transient heating. 2nd heating series

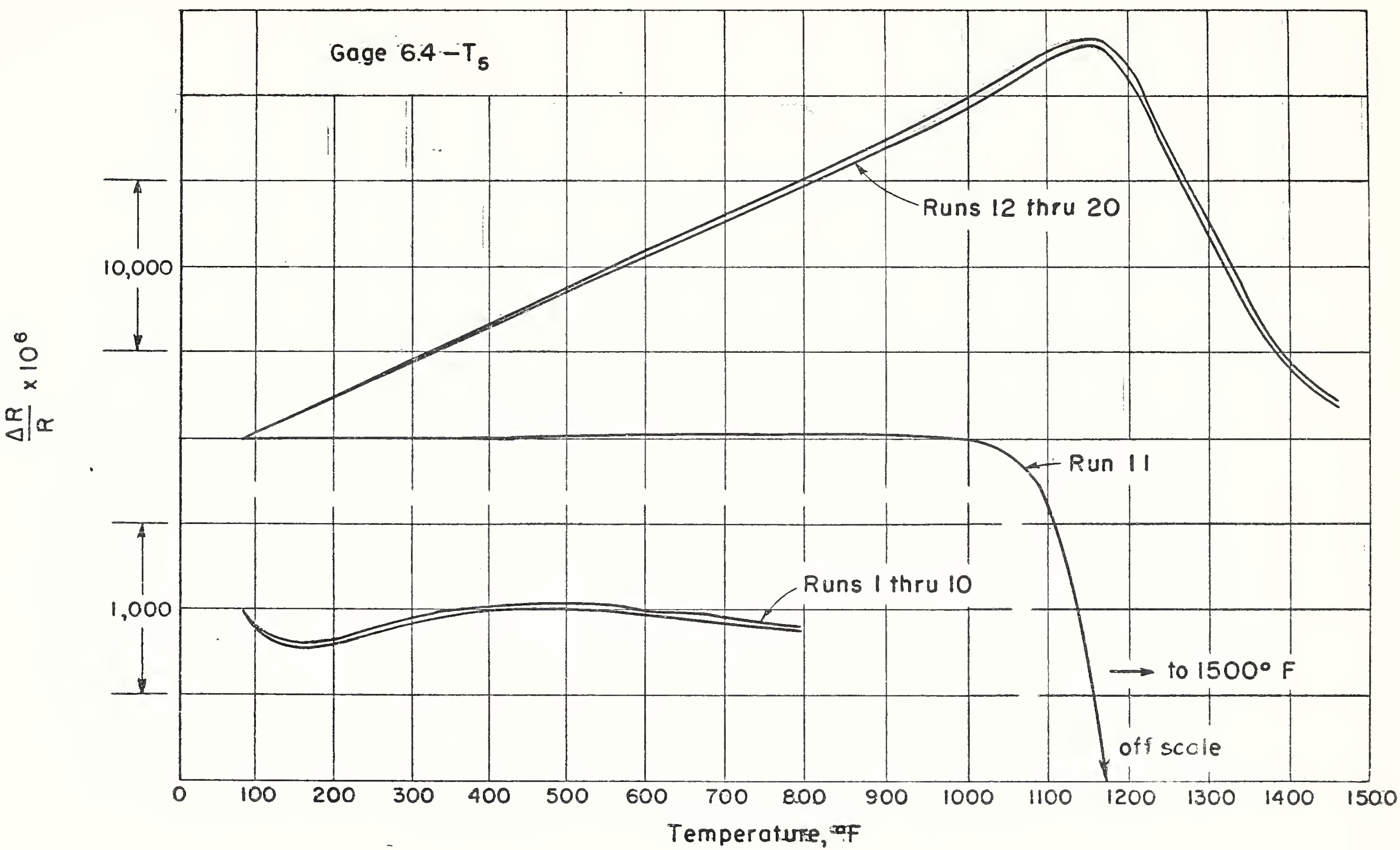

Fig. 28 Variation of gage response with transient heating

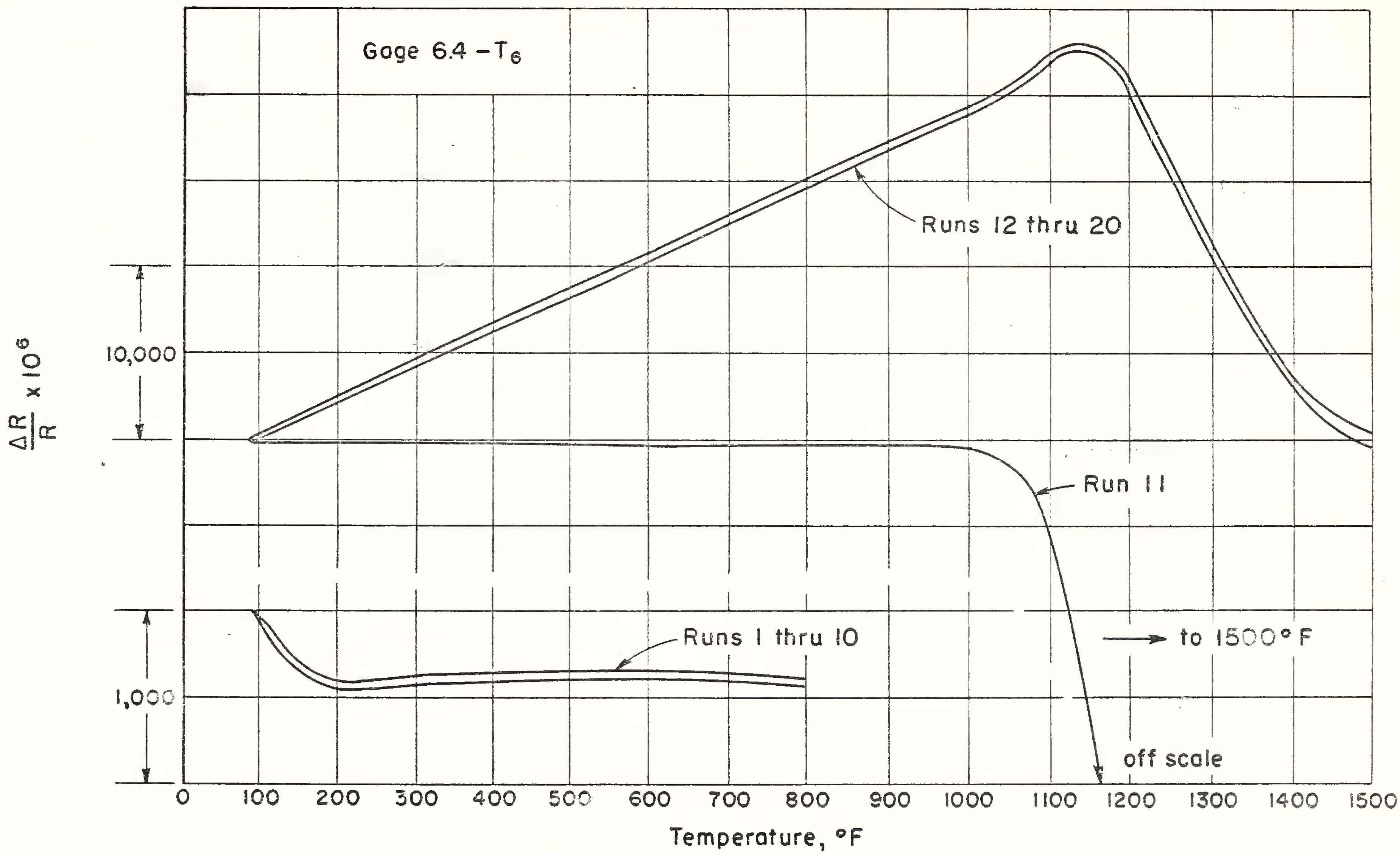

Fig. 29 Variation of gage response with transient heating

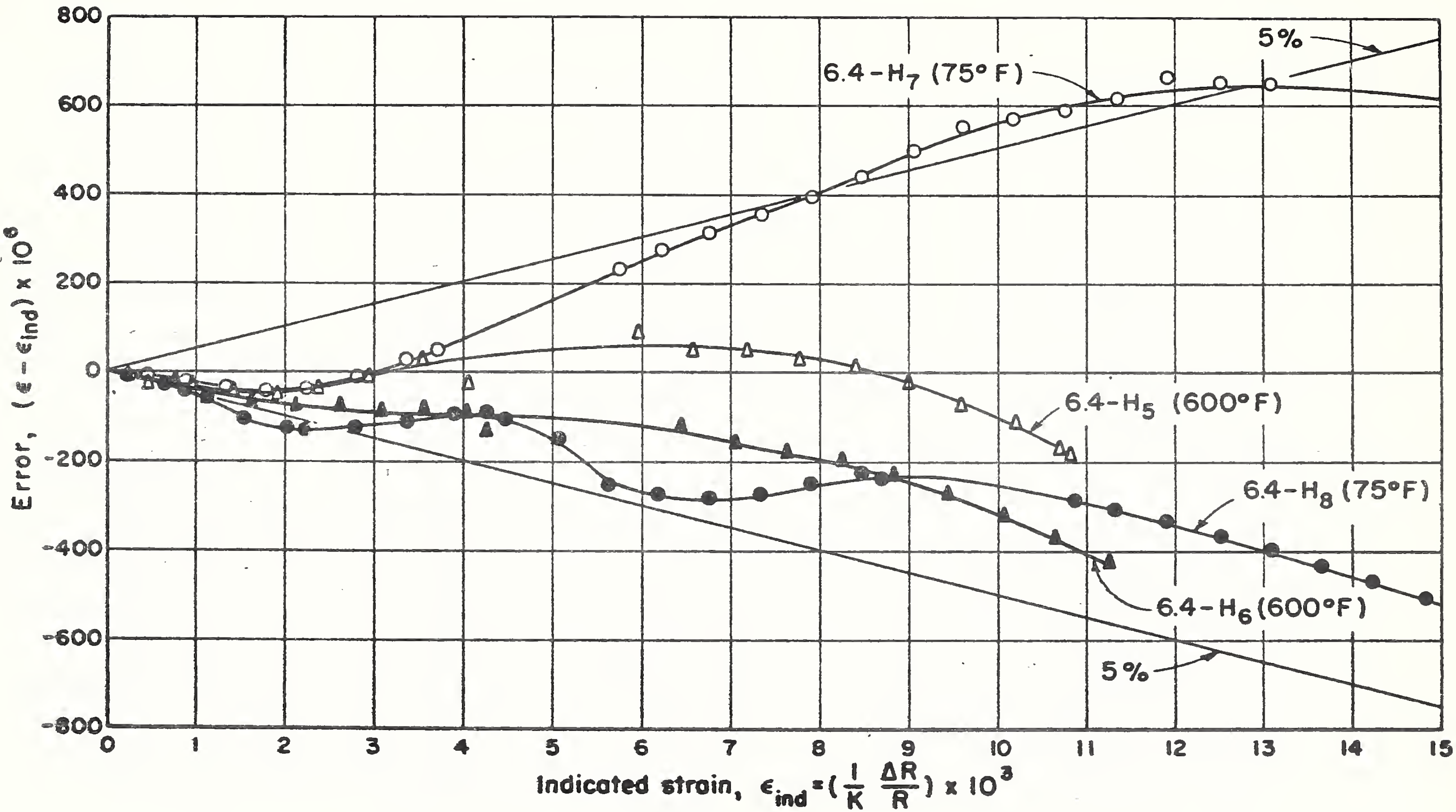

Fig. 30 Gage behavior at high strains.

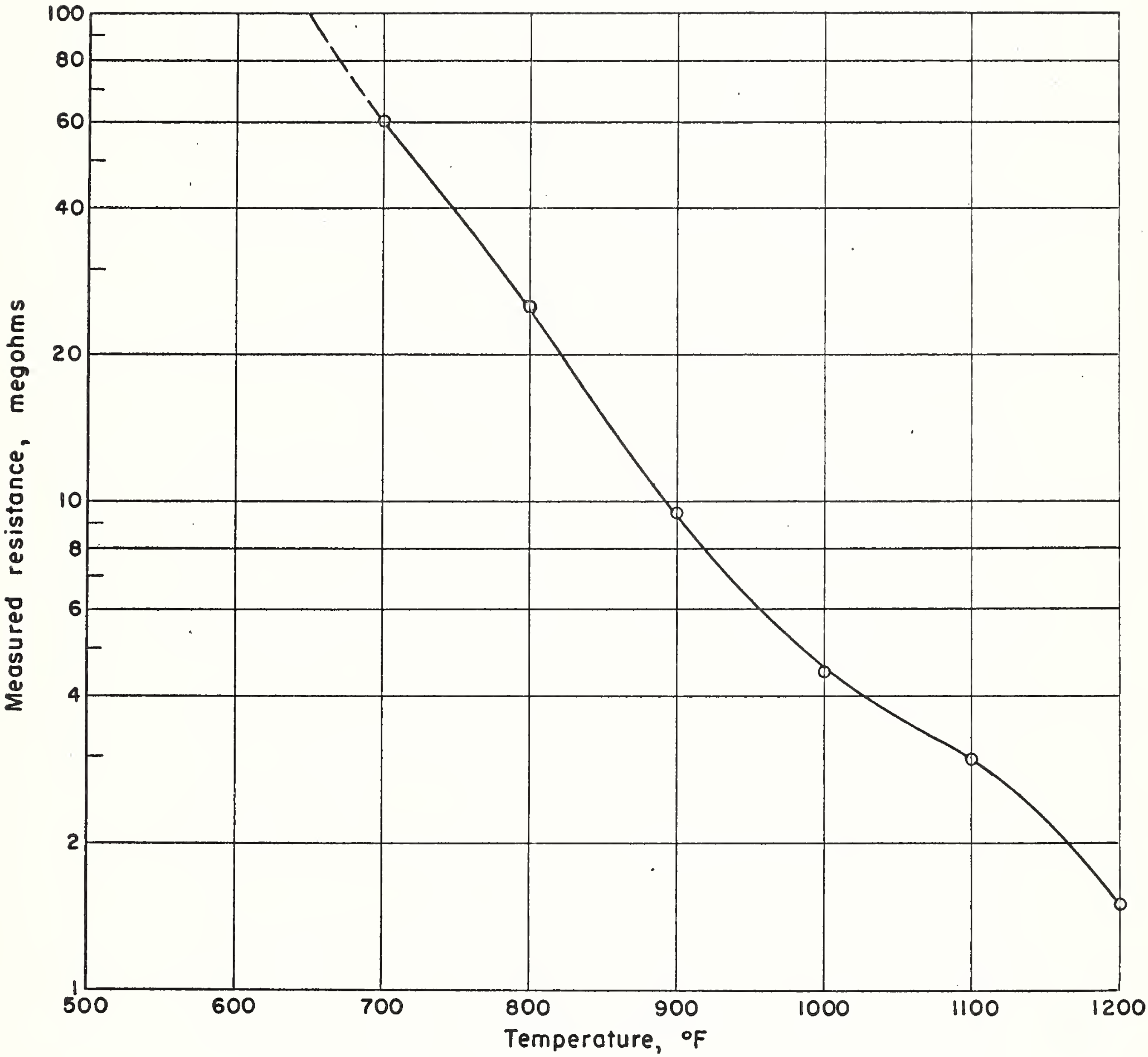

Fig. 31 Resistance between gage and test strip

DISTRIBUTION LIST

U. S. Government Agencies

Chief, Bureau of Aeronautics (AD-222) Washington 25, D. C.	4
Commander, Wright Air Development Center (Code WCLSS) Wright-Patterson Air Force Base, Ohio	6
Commander, Wright Air Development Center (Code MCPHCA) Wright-Patterson Air Force Base, Ohio	1
Commander, Wright Air Development Center (Code WCRTL-4) Wright-Patterson Air Force Base, Ohio	1
Director, National Aeronautics and Space Administration 1520 H Street, N. W. Washington 25, D. C.	5
Director, National Aeronautics and Space Administration Langley Research Center Langley Field, Virginia Attn: Mr. J. Munick	1
Director, National Aeronautics and Space Administration Lewis Research Center Cleveland 11, Ohio	1
Commanding General Aberdeen Proving Ground, Maryland Attn: Technical Library	1
Commander, Air Research and Development Command Andrews Air Force Base, Maryland	2
Commanding Officer Air Force Flight Test Center Attn: FTOTL Edwards Air Force Base, Calif.	1
U. S. Atomic Energy Commission Technical Information Service P. O. Box 62 Oak Ridge, Tennessee	1
U. S. Department of Agriculture Madison Branch Forest Products Laboratory Madison 5, Wisconsin	1
Chief, Bureau of Ships (Code 548) Washington 25, D. C.	3
Commanding Officer, Naval Air Material Center (ASL) Philadelphia 12, Pennsylvania Attn: Mr. D. Weiss	2
Office of Naval Research (Mechanics Branch Code 438) Washington 25, D. C.	2
Naval Boiler and Turbine Laboratory Philadelphia Naval Base Philadelphia 12, Pennsylvania Attn: Mr. Murdock, Instrumentation Division	1
Naval Research Laboratory Anacostia, D. C.	2
Oak Ridge National Laboratory Oak Ridge, Tennessee Attn: Mr. H. J. Metz, Instrument Department	1
Commanding General, Redstone Arsenal Huntsville, Alabama Attn: Technical Library	2
Commander, Armed Services Technical Information Agency Attn: TIPDR Arlington Hall Station Arlington 12, Virginia	5

Springfield Armory
Federal Street
Springfield, Massachusetts
Attn: Mr. Salame 1

National Bureau of Standards
Enameled Metals Section
Washington 25, D. C. 1

Other Agencies

Aerolab Development Company, Inc.
330 W. Holly Street
Pasadena 3, California 1

Aeronutronics Systems, Inc.
1234 Air Way
Glendale, California
Attn: G. J. Pastor 1

AIResearch Manufacturing Company
of Arizona
402 S. 36th Street
Phoenix, Arizona 1

Allied Research Associates, Inc.
43 Leon Street
Boston 15, Massachusetts
Attn: Mr. D. Franklin 1

Allison Division
General Motors Corp.
Indianapolis 6, Indiana 1

American Instrument Company
Silver Spring, Maryland 1

A. O. Smith Corporation
Milwaukee 1, Wisconsin
Attn: Research Library 1

Armour Research Foundation
Illinois Institute of Technology
Technology Center
Chicago 16, Illinois
Attn: Mr. W. Graft 1

ARO, Inc.
Tullahoma, Tennessee
Attn: Mr. H. K. Matt 1

Atomic Instrument Company
84 Massachusetts Avenue
Cambridge 39, Massachusetts 1

Atomics International
A Division of North American
Aviation, Inc.
P. O. Box 309
Canoga Park, California 1

Atomic Power Development
Associates, Inc.
1911 First Street
Detroit 26, Michigan
Attn: Mr. F. R. Beyer 1

Baldwin-Lima-Hamilton Corp.
Electronics and Instrumentation
Division
42 Fourth Avenue
Waltham 54, Massachusetts 1

Beech Aircraft Corporation
Wichita, Kansas 1

Bell Aircraft Corporation
Niagara Falls, New York 1

Bell Aircraft Corporation
Fort Worth, Texas 1

Bendix Products Division -
Missiles
Bendix Aviation Corporation
Mishawaka, Indiana
Attn: George T. Cramer 1

Benson-Lehner Corporation
West Los Angeles, California 1

B. J. Electronics
P. O. Box 1679
Santa Ana, California 1

Boeing Airplane Company
Seattle, Washington 1

Boeing Airplane Company
Wichita, Kansas 1

Bulova Research & Development Laboratories, Inc.
62-10 Woodside Avenue
Woodside 77, New York 1

Cessna Aircraft Company
Wichita, Kansas 1

Chance Vought Aircraft, Inc.
Dallas, Texas 1

Columbia Research Laboratories
MacDade Blvd. and Bullens Lane
Woodlyn, Pennsylvania 1

Combustion Engineering, Inc.
Chattanooga Division
Chatanooga 1, Tennessee 1

Consolidated Engineering Corporation
300 N. Sierra Madre Villa
Pasadena 15, California 1

Consolidated Electrodynamics Corporation
Strain Gage Products Transducer Division
1400 South Shamrock Avenue
Monrovia, California
Attn: Robert E. Stanaway 1

Convair, A Division of General Dynamics Corporation
San Diego, California 1

Convair, A Division of General Dynamics Corporation
Fort Worth, Texas 1

Cook Research Laboratories
6401 Oakton Street
Morton Grove, Illinois 1

Cornell Aeronautical Laboratory, Inc.
Structural Laboratory Section
Buffalo 21, New York
Attn: Mr. J. E. Carpenter 1

Curtiss-Wright Corporation
Test Instrumentation & Equipment Division
Wood-Ridge, New Jersey
Attn: Mr. Neil Eisen 1

Curtiss-Wright Corporation
Propeller Division
Caldwell, New Jersey 1

Douglas Aircraft Company, Inc.
Santa Monica, California 1

Douglas Aircraft Company, Inc.
El Segundo, California 1

Douglas Aircraft Company, Inc.
Long Beach, California 1

Esso Research and Engineering Co.
P. O. Box 8
Linden, New Jersey
Attn: Design Engineering Division 1

Fairchild Aircraft Division
Fairchild Engine and Airplane Corporation
Hagerstown, Maryland 1

Fairchild Engine Division
Fairchild Engine and Airplane Corporation
Deer Park, Long Island, New York 1

Fielden Instrument Division
Robert Shaw-Fulton Controls Co.
2920 N. 4th Street
Philadelphia 33, Pennsylvania 1

Fluor Products Company
P. O. Box 510
Whittier, California 1

Foster Wheeler Corporation
165 Broadway
New York 6, New York 1

General Electric Company
ANP Department
Cincinnati 15, Ohio 1

General Electric Company
General Engineering Laboratory
Schenectady, New York
Attn: Mr. D. DeMichele 1

General Electric Company
Aircraft Gas Turbine Division
Cincinnati 15, Ohio 1

General Electric Company
Special Products Division
30th and Walnut Streets
Philadelphia, Pennsylvania
Attn: Mr. M. Bennon 1

General Electric Company
Missile and Ordnance Systems
Department
3198 Chestnut Street
Philadelphia 4, Pennsylvania 1

Gilmore Technical Associates
Cleveland, Ohio 1

Goodyear Aircraft Corporation
Akron 15, Ohio 1

Grumman Aircraft Engineering
Corporation
Bethpage, Long Island, New York 1

High Temperature Instruments
Corp.
No. 1 Highland Avenue
Balla Cynwyd, Pennsylvania 1

HITEMP Wires, Inc.
26 Windsor Avenue
Mineola, New York 1

J. T. Hill Company
420 S. Pine Street
San Gabriel, California 1

Lockheed Aircraft Corporation
Burbank, California
Attn: Mr. W. Brewer, Research
Dept. 1

Lockheed Aircraft Corporation
Georgia Division
Marietta, Georgia
Attn: Engr. Tech. Library 1

Lockheed Aircraft Corporation
Missiles Systems Division
Van Nuys, California 1

Lycoming Division
AVCO Manufacturing Corporation
Stratford, Connecticut
Attn: Mr. R. Hohenberg 1

Magnavox Research Laboratories
Los Angeles, California
Attn: Mr. J. Francis 1

Massachusetts Institute of
Technology
Laboratory for Insulation Research
Cambridge 39, Massachusetts 1

McDonnell Aircraft Corporation
St. Louis, Missouri 1

Mr. Given A. Brewer
Consulting Engineer
Marion, Massachusetts 1

Micro-Test, Inc.
657 N. Spaulding Avenue
Los Angeles, California 1

Mithra Engineering Company
P. O. Box 1294
Beverly Hills, California 1

National Electronics Laboratories, Inc.
1713 Kalorama Road, N. W.
Washington 9, D. C. 1

North American Aviation, Inc.
Structures Engineering Department
Inglewood, California 1

North American Aviation, Inc.
Columbus, Ohio 1

Northrop Aircraft, Inc.
Hawthorne, California 1

Pennsylvania State College
University Park, Pennsylvania 1

Polytechnic Institute of Brooklyn
99 Livingston Street
Brooklyn 1, New York
Attn: Mr. N. J. Hoff 1

Research Librarian
Portland Cement Association
5420 Old Orchard Road
Skokie, Illinois 1

Pratt and Whitney Aircraft Division
United Aircraft Corporation
East Hartford, Connecticut
Attn: Mr. G. E. Beardsley, Jr. 1

Radiation Incorporated
Instrumentation Division
P. O. Box 2040, Pine Castle Branch
Orlando, Florida
Attn: Mr. U. R. Barnett 1

Republic Aviation Company
Farmingdale, Long Island,
New York 1

Research, Incorporated
115 N. Buchanan Avenue
Hopkins, Minnesota
Attn: Mr. F. G. Anderson 1

Ryan Aeronautical Company
San Diego, California 1

Solar Aircraft Company
2200 Pacific Highway
San Diego 12, California 1

Southwest Research Institute
8500 Culebra Road
San Antonio 6, Texas 1

Statham Laboratories, Inc.
12401 W. Olympic Blvd.
Los Angeles 64, California 1

Stratos Division
Fairchild Engine and Airplane Corporation
Bay Shore, L. K., New York 1

Systems Research Laboratories, Inc.
300 Woods Drive
Dayton 32, Ohio
Attn: R. A. Johnson 1

Temco Aircraft Corporation
Dallas, Texas 1

The Martin Company
Baltimore, Maryland 1

The Martin Company
Denver 1, Colorado 1

The Society for Experimental Stress Analysis
Central Square Station
P. O. Box 168
Cambridge 39, Massachusetts 1

The Tatnall Measuring Systems Co.
P. O. Box 235
Phoenixville, Pennsylvania
Attn: Mr. Frank Tatnall 1

Thiokol Chemical Corporation
Utah Division
Brigham City, Utah
Attn: Instrumentation Engineering
Unit 1

Trans-Sonics, Inc.
P. O. Box 328
Lexington 73, Massachusetts 1

University of Colorado
Boulder, Colorado
Attn: Prof. F. C. Walz 1

University of Dayton Research
Institute
Special Projects Division
Dayton 9, Ohio
Attn: E. A. Young 1

University of New Mexico
Engineering Experiment Station
Albuquerque, New Mexico 1

Waldale Research Company, Inc.
362 West Colorado Blvd
Pasadena, California
Attn: Mr. F. N. Singdale, Pres. 1

Westinghouse Electric Corporation
Atomic Power Division
Pittsburgh, Pennsylvania 1

Westinghouse Electric Corporation
Materials Engineering Department,
K-70, Performance Laboratory
East Pittsburgh, Pennsylvania 1

Westinghouse Electric Corp., AGT
Engineering Library
P. O. Box 288
Kansas City, Missouri 1

Professor H. H. Bleich
(NR 064-417)
Department of Civil Engineering
Columbia University
Broadway at 117 Street
New York 27, New York 1

Professor D. C. Drucker
(NR 064-424)
Division of Engineering
Brown University
Providence 12, Rhode Island 1

Professor N. J. Hoff
(NR 064-425)
Division of Aeronautical
Engineering
Stanford University
Stanford, California 1

Professor Joseph Kempner
(NR 064-433)
Department of Aeronautical
Engineering and Applied
Mechanics
Polytechnic Institute of Brooklyn
333 Jay Street
Brooklyn 1, New York 1

Mr. Peter Stein
5602 E. Monte Rosa
Phoenix, Arizona 1

Bristol Aircraft Limited
Electronic and Vibration
Laboratory - E. D. L.
Filton House
Bristol, England 1

U.S. DEPARTMENT OF COMMERCE
Frederick H. Mueller, Secretary

NATIONAL BUREAU OF STANDARDS
A. V. Astin, *Director*

THE NATIONAL BUREAU OF STANDARDS

The scope of activities of the National Bureau of Standards at its headquarters in Washington, D.C., and its major laboratories in Boulder, Colorado, is suggested in the following listing of the divisions and sections engaged in technical work. In general, each section carries out specialized research, development, and engineering in the field indicated by its title. A brief description of the activities, and of the resultant publications, appears on the inside of the front cover.

WASHINGTON, D.C.

Electricity and Electronics. Resistance and Reactance. Electron Devices. Electrical Instruments. Magnetic Measurements. Dielectrics. Engineering Electronics. Electronic Instrumentation. Electrochemistry.

Optics and Metrology. Photometry and Colorimetry. Optical Instruments. Photographic Technology. Length. Engineering Metrology.

Heat. Temperature Physics. Thermodynamics. Cryogenic Physics. Rheology. Engine Fuels. Free Radicals Research.

Atomic and Radiation Physics. Spectroscopy. Radiometry. Mass Spectrometry. Solid State Physics. Electron Physics. Atomic Physics. Neutron Physics. Radiation Theory. Radioactivity. X-rays. High Energy Radiation. Nucleonic Instrumentation. Radiological Equipment.

Chemistry. Organic Coatings. Surface Chemistry. Organic Chemistry. Analytical Chemistry. Inorganic Chemistry. Electrodeposition. Molecular Structure and Properties of Gases. Physical Chemistry. Thermochemistry. Spectrochemistry. Pure Substances.

Mechanics. Sound. Mechanical Instruments. Fluid Mechanics. Engineering Mechanics. Mass and Scale. Capacity, Density, and Fluid Meters. Combustion Controls.

Organic and Fibrous Materials. Rubber. Textiles. Paper. Leather. Testing and Specifications. Polymer Structure. Plastics. Dental Research.

Metallurgy. Thermal Metallurgy. Chemical Metallurgy. Mechanical Metallurgy. Corrosion. Metal Physics.

Mineral Products. Engineering Ceramics. Glass. Refractories. Enameled Metals. Concreting Materials. Constitution and Microstructure.

Building Technology. Structural Engineering. Fire Protection. Air Conditioning, Heating, and Refrigeration. Floor, Roof, and Wall Coverings. Codes and Safety Standards. Heat Transfer.

Applied Mathematics. Numerical Analysis. Computation. Statistical Engineering. Mathematical Physics.

Data Processing Systems. SEAC Engineering Group. Components and Techniques. Digital Circuitry. Digital Systems. Analog Systems. Application Engineering.

- Office of Basic Instrumentation.
- Office of Weights and Measures.

BOULDER, COLORADO

Cryogenic Engineering. Cryogenic Equipment. Cryogenic Processes. Properties of Materials. Gas Liquefaction.

Radio Propagation Physics. Upper Atmosphere Research. Ionospheric Research. Regular Propagation Services. Sun-Earth Relationships. VHF Research. Radio Warning Services. Airglow and Aurora. Radio Astronomy and Arctic Propagation.

Radio Propagation Engineering. Data Reduction Instrumentation. Modulation Systems. Radio Noise. Tropospheric Measurements. Tropospheric Analysis. Radio Systems Application Engineering. Radio-Meteorology. Lower Atmosphere Physics.

Radio Standards. High Frequency Electrical Standards. Radio Broadcast Service. High Frequency Impedance Standards. Electronic Calibration Center. Microwave Physics. Microwave Circuit Standards.

Radio Communication and Systems. Low Frequency and Very Low Frequency Research. High Frequency and Very High Frequency Research. Ultra High Frequency and Super High Frequency Research. Modulation Research. Antenna Research. Navigation Systems. Systems Analysis. Field Operations.

NBS